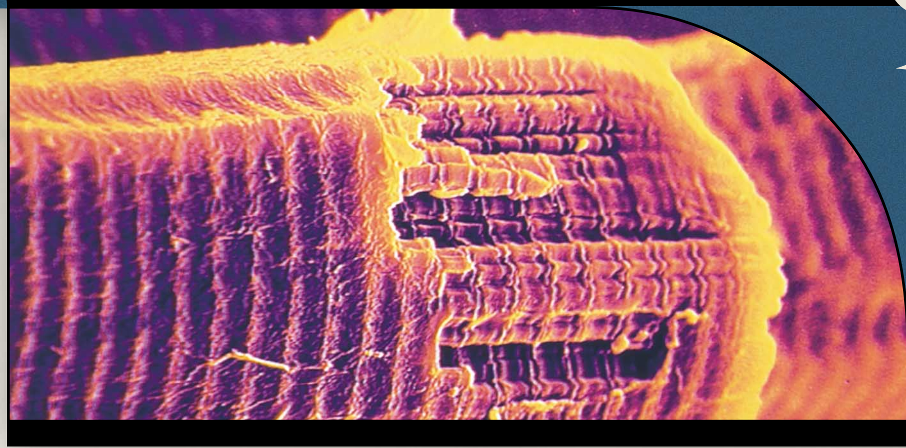


Falsely colored scanning electron micrograph (SEM) of normal human striated muscle fibers, revealing the characteristic banding pattern of the constituent myofibrils. (1750×)

Muscular System

UNDERSTANDING WORDS

calat-, something inserted: inter*calat*ed disc—membranous band that connects cardiac muscle cells.

erg-, work: syn*erg*ist—muscle that works together with a prime mover to produce a movement.

fasc-, bundle: *fasc*iculus—bundle of muscle fibers.

-gram, something written: myo*gram*—recording of a muscular contraction.

hyper-, over, more: muscular *hyper*trophy—enlargement of muscle fibers.

inter-, between: *inter*calated disc—membranous band that connects cardiac muscle cells.

iso-, equal: *iso*tonic contraction—contraction during which the tension in a muscle remains unchanged.

laten-, hidden: *laten*t period—period between a stimulus and the beginning of a muscle contraction.

myo-, muscle: *myo*fibril—contractile fiber of a muscle cell.

reticul-, a net: sarcoplasmic *reticul*um—network of membranous channels within a muscle fiber.

sarco-, flesh: *sarco*plasm—substance (cytoplasm) within a muscle fiber.

syn-, together: *syn*ergist—muscle that works with a prime mover to produce a movement.

tetan-, stiff: *tetan*ic contraction—sustained muscular contraction.

-tonic, stretched: iso*tonic* contraction—contraction during which the tension of a muscle remains unchanged.

-troph, well fed: muscular hyper*troph*y—enlargement of muscle fibers.

voluntar-, of one's free will: *voluntar*y muscle—muscle that can be controlled by conscious effort.

CHAPTER OBJECTIVES

After you have studied this chapter, you should be able to

1. Describe how connective tissue is part of the structure of a skeletal muscle.
2. Name the major parts of a skeletal muscle fiber and describe the function of each part.
3. Explain the major events that occur during muscle fiber contraction.
4. Explain how energy is supplied to the muscle fiber contraction mechanism, how oxygen debt develops, and how a muscle may become fatigued.
5. Distinguish between fast and slow twitch muscle fibers.
6. Distinguish between a twitch and a sustained contraction.
7. Describe how exercise affects skeletal muscles.
8. Explain how various types of muscular contractions produce body movements and help maintain posture.
9. Distinguish between the structures and functions of a multiunit smooth muscle and a visceral smooth muscle.
10. Compare the contraction mechanisms of skeletal, smooth, and cardiac muscle fibers.
11. Explain how the locations of skeletal muscles help produce movements and how muscles interact.
12. Identify and locate the major skeletal muscles of each body region and describe the action of each muscle.

Like many things in life, individual muscles aren't appreciated until we see what happens when they do not work. For children with Moebius syndrome, absence of the sixth and seventh cranial nerves, which carry impulses from the brain to the muscles of the face, leads to an odd collection of symptoms.

The first signs of Moebius syndrome are typically difficulty sucking, excessive drooling, and sometimes crossed eyes. The child has difficulty swallowing and chokes easily, cannot move the tongue well, and is very sensitive to bright light because he or she cannot squint or blink or even avert the eyes. Special bottles and feeding tubes can help the child eat, and surgery can correct eye defects.

Children with Moebius syndrome are slow to reach developmental milestones but do finally walk. As they get older, if they are lucky, they are left with only one symptom, but it is a rather obvious one—inability to form facial expressions.

A young lady named Chelsey Thomas called attention to this very rare condition when she underwent two surgeries that would enable her

to smile. In 1995 and 1996, when she was seven years old, Chelsey had two transplants of nerve and muscle tissue from her legs to either side of her mouth, supplying the missing "smile apparatus." Gradually, she acquired the subtle, and not-so-subtle, muscular movements of the mouth that make the human face so expressive. Chelsey inspired several other youngsters to undergo "smile surgery." Publicity about her surgery informed many health care professionals about this extremely rare condition. ■

The three types of muscle tissues are skeletal, smooth, and cardiac, as described in chapter 5 (pages 148–150). This chapter focuses on the skeletal muscles, which are usually attached to bones and are under conscious control.

Structure of a Skeletal Muscle

A skeletal muscle is an organ of the muscular system. It is composed primarily of skeletal muscle tissue, nervous tissue, blood, and connective tissues.

Connective Tissue Coverings

An individual skeletal muscle is separated from adjacent muscles and held in position by layers of dense connective tissue called **fascia** (fash′e-ah). This connective tissue surrounds each muscle and may project beyond the end of its muscle fibers to form a cordlike **tendon.** Fibers in a tendon intertwine with those in the periosteum of a bone, attaching the muscle to the bone. In other cases, the connective tissues associated with a muscle form broad, fibrous sheets called **aponeuroses** (ap″o-nu-ro′sēz), which may attach to bone, or, in some cases, the coverings of adjacent muscles (figs. 9.1 and 9.2).

The layer of connective tissue that closely surrounds a skeletal muscle is called the *epimysium.* Another layer of connective tissue, called the *perimysium,* extends inward from the epimysium and separates the muscle tissue into small sections. These sections contain bundles of skeletal muscle fibers called *fascicles* (fasciculi). Each muscle fiber within a fascicle (fasciculus) lies within a layer of connective tissue in the form of a thin covering called *endomysium* (figs. 9.2 and 9.3). Layers of connective tissue, therefore, enclose and separate all parts of a skeletal muscle. This arrangement allows the parts to move somewhat independently. Also, many blood vessels and nerves pass through these layers.

A tendon or the connective tissue sheath of a tendon (tenosynovium) may become painfully inflamed and swollen following an injury or the repeated stress of athletic activity. These conditions are called *tendinitis* and *tenosynovitis,* respectively. The tendons most commonly affected are those associated with the joint capsules of the shoulder, elbow, hip, and knee and those involved with moving the wrist, hand, thigh, and foot.

A *compartment* is the space that contains a particular group of muscles, blood vessels, and nerves, all tightly enclosed by fascia. The limbs have many such compartments. If an injury causes fluid, such as blood from an internal hemorrhage, to accumulate within a compartment, the pressure inside will rise. The increased pressure, in turn, may interfere with blood flow into the region, reducing the supply of oxygen and nutrients to the affected tissues. This condition, called *compartment syndrome,* often produces severe, unrelenting pain. Persistently elevated compartmental pressure may irreversibly damage the enclosed muscles and nerves. Treatment for compartment syndrome may require immediate intervention by a surgical incision through the fascia (fasciotomy) to relieve the pressure and restore circulation.

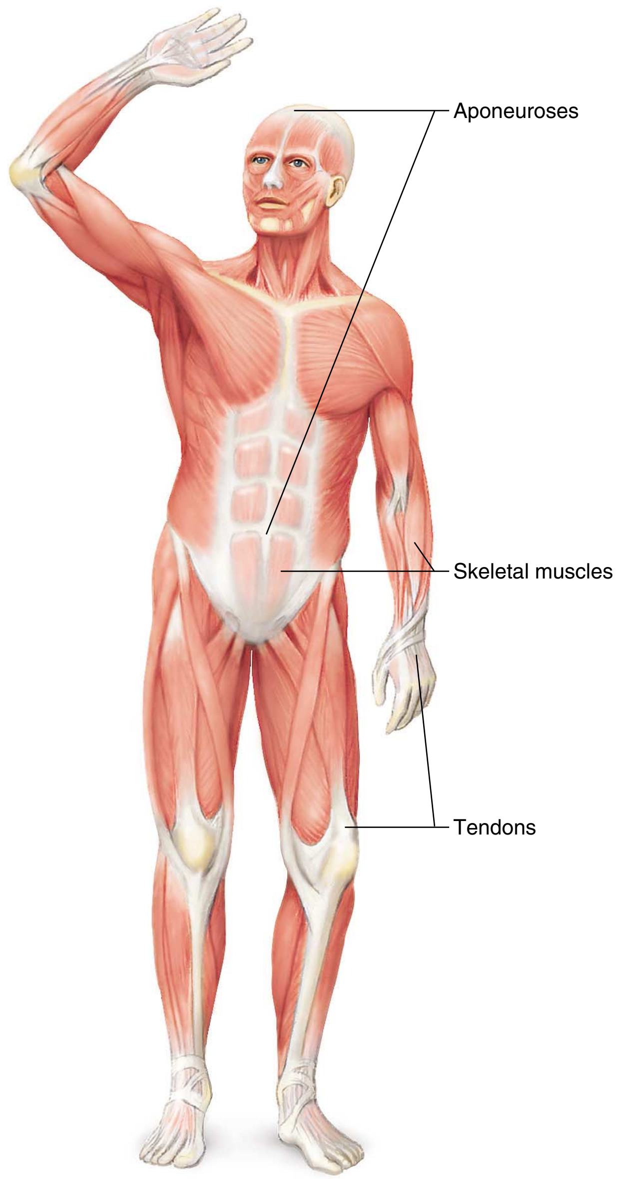


FIGURE 9.1
Tendons attach muscles to bones, whereas aponeuroses attach muscles to other muscles.

The fascia associated with each individual organ of the muscular system is part of a complex network of fasciae that extends throughout the body. The portion of the network that surrounds and penetrates the muscles is called *deep fascia.* It is continuous with the *subcutaneous fascia* that lies just beneath the skin, forming the subcutaneous layer described in chapter 6 (p. 164). The network is also continuous with the *subserous fascia* that forms the connective tissue layer of the serous membranes covering organs in various body cavities and lining those cavities (see chapter 5, p. 152).

Skeletal Muscle Fibers

Recall from chapter 5 (p. 148) that a skeletal muscle fiber is a single muscle cell (see fig. 5.28). Each fiber forms from many undifferentiated cells that fuse during development. Each resulting multinucleated muscle fiber is a thin, elongated cylinder with rounded ends that attach to the connective tissues associated with a muscle. Just beneath the muscle cell membrane (*sarcolemma*), the cytoplasm (*sarcoplasm*) of the fiber contains many small, oval nuclei and mitochondria. The sarcoplasm also has abundant, parallel, threadlike structures called **myofibrils** (mi″o-fi′-brilz) (fig. 9.4*a*)

The myofibrils play a fundamental role in the muscle contraction mechanism. They contain two kinds of protein filaments: Thick filaments composed of the protein **myosin** (mi′o-sin), and thin filaments composed primarily of the protein **actin** (ak′tin). (Two other thin filament proteins, troponin and tropomyosin, will be discussed later.) The organization of these filaments produces the alternating light and dark striations characteristic of skeletal muscle (and cardiac muscle) fibers. The striations form a repeating pattern of units called **sarcomeres** (sar′ko-mērz) along each muscle fiber. The myofibrils may be thought of as sarcomeres joined end to end. (fig. 9.4*a*).

The striation pattern of skeletal muscle has two main parts. The first, the *I bands* (the light bands), are composed of thin actin filaments held by direct attachments to structures called *Z lines,* which appear in the center of the I bands. The second part of the striation pattern consists of the *A bands* (the dark bands), which are composed of thick myosin filaments overlapping thin actin filaments (fig. 9.4*b*).

Note that the A band consists not only of a region where thick and thin filaments overlap, but also a slightly lighter central region (*H zone*) consisting only of thick filaments. The A band includes a thickening known as the *M line,* which consists of proteins that help hold the thick filaments in place (fig. 9.4*b*). The myosin filaments are also held in place by the Z lines but are attached to them by a large protein called **titin** (connectin) (fig. 9.5). A sarcomere extends from one Z line to the next.

Thick filaments are composed of many molecules of myosin. Each myosin molecule consists of two twisted protein strands with globular parts called *cross-bridges* (heads) that project outward along their lengths. Thin filaments consist of double strands of actin twisted into a helix. Actin molecules are globular, and each has a binding site to which the cross-bridges of a myosin molecule can attach (fig. 9.6).

Two other types of protein, **troponin** and **tropomyosin,** associate with actin filaments. Troponin molecules have three protein subunits and are attached to actin. Tropomyosin molecules are rod-shaped and occupy the longitudinal grooves of the actin helix. Each tropomyosin is held in place by a troponin molecule, forming a tropomyosin-troponin complex (fig. 9.6).

Within the sarcoplasm of a muscle fiber is a network of membranous channels that surrounds each myofibril and runs parallel to it. These membranes form the **sarcoplasmic reticulum,** which corresponds to the endoplasmic

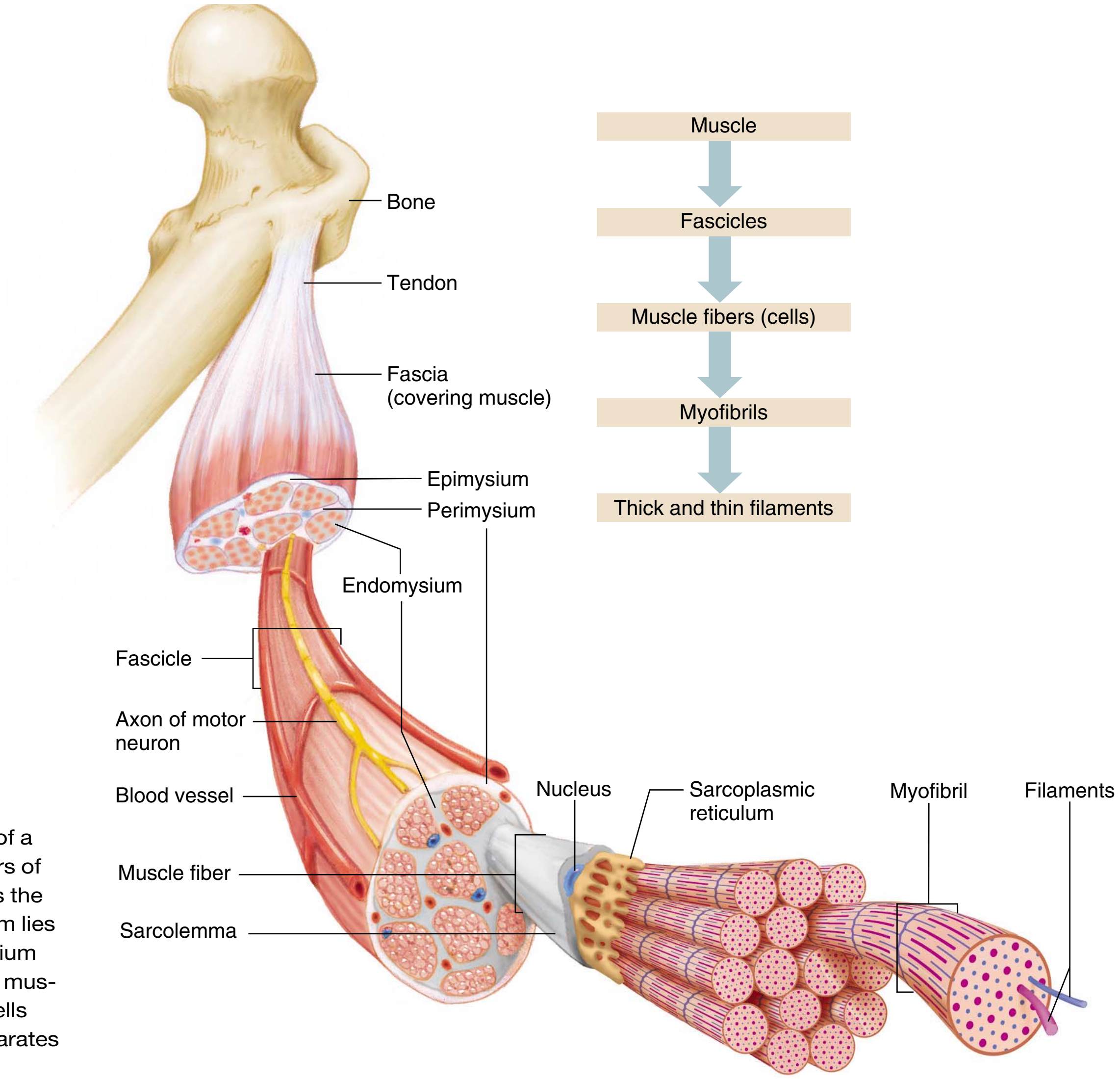


FIGURE 9.2
A skeletal muscle is composed of a variety of tissues, including layers of connective tissue. Fascia covers the surface of the muscle, epimysium lies beneath the fascia, and perimysium extends into the structure of the muscle where it separates muscle cells into fascicles. Endomysium separates individual muscle fibers.

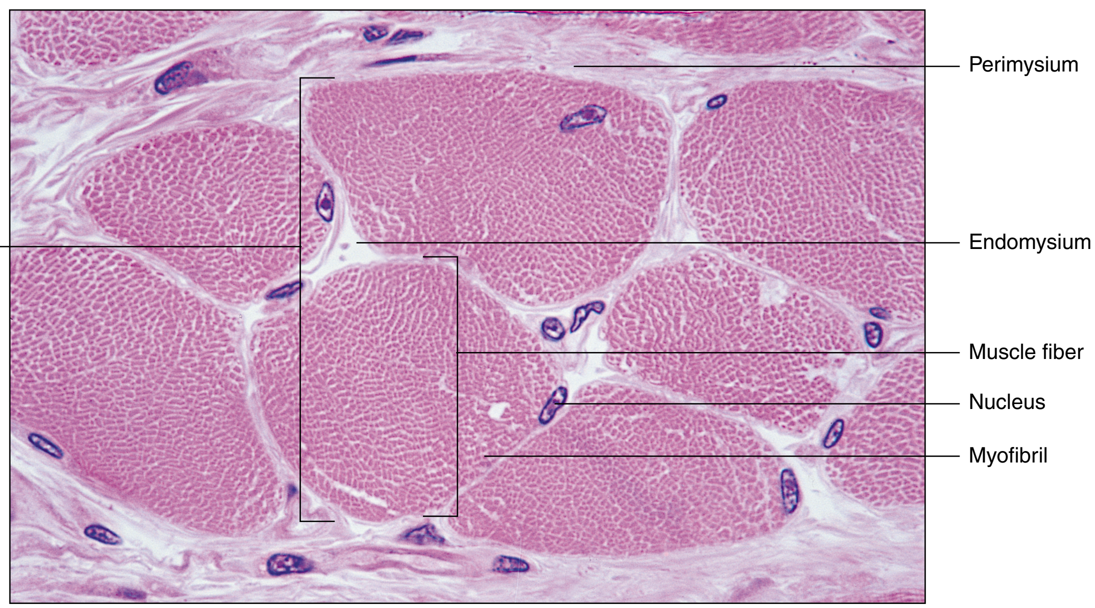


FIGURE 9.3
Scanning electron micrograph of a fascicle (fasciculus) surrounded by its connective tissue sheath, the perimysium. Muscle fibers within the fascicle are surrounded by endomysium (320×).

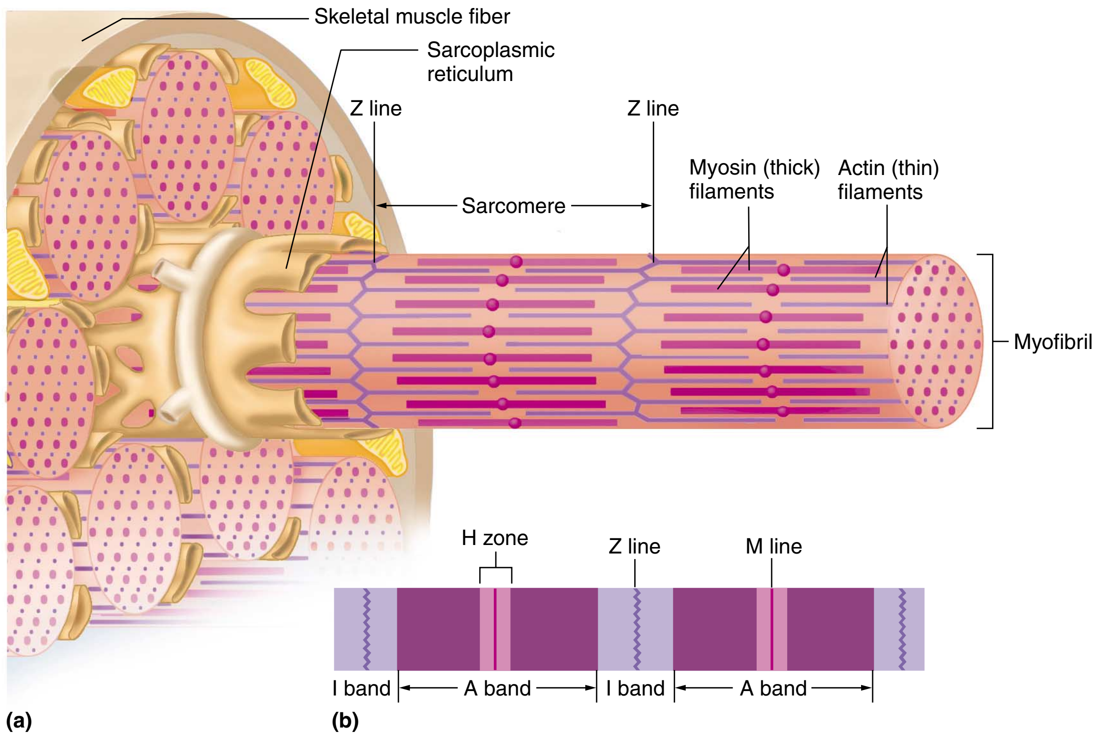


FIGURE 9.4
Skeletal muscle fiber. (*a*) A skeletal muscle fiber contains numerous myofibrils, each consisting of (*b*) repeating units called sarcomeres. The characteristic striations of a sarcomere reflect the organization of actin and myosin filaments.

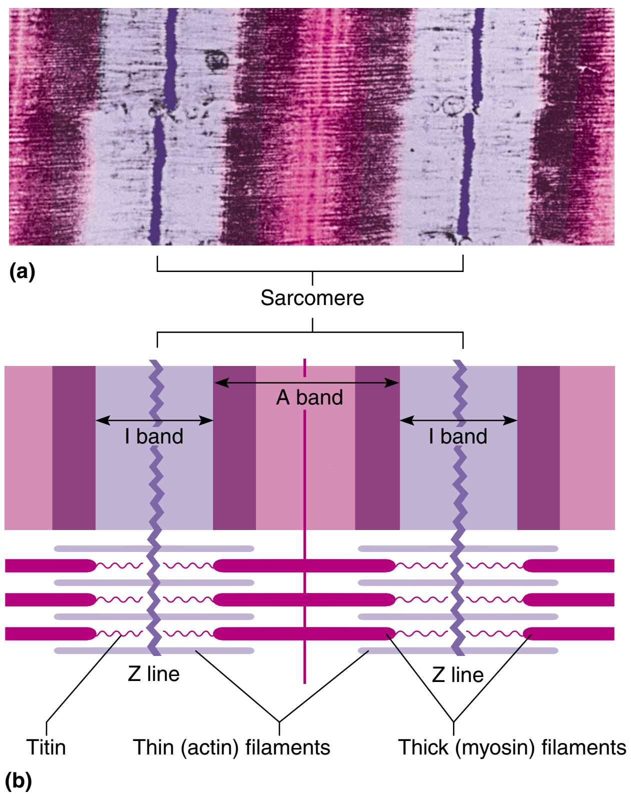


FIGURE 9.5
A sarcomere (16,000×).

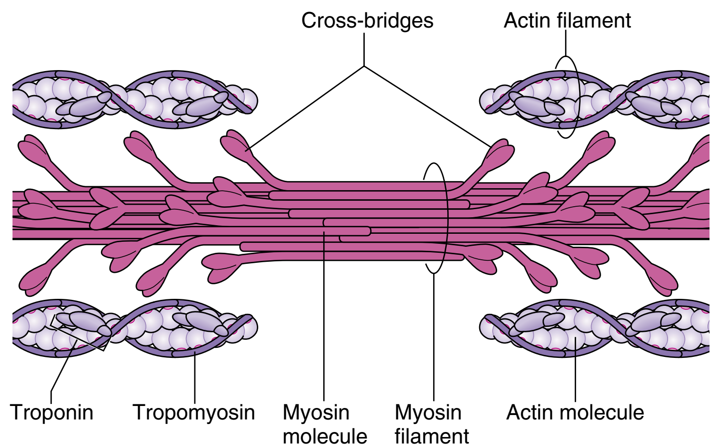


FIGURE 9.6
Thick filaments are composed of the protein myosin, and thin filaments are composed of the protein actin. Myosin molecules have cross-bridges that extend toward nearby actin filaments.

reticulum of other cells (see figs. 9.2 and 9.4). A set of membranous channels, the **transverse tubules** (T-tubules), extends into the sarcoplasm as invaginations continuous with the sarcolemma and contains extracellular fluid. Each transverse tubule lies between two enlarged portions of the sarcoplasmic reticulum called **cisternae,** and these three structures form a **triad** near the region where the actin and myosin filaments overlap (fig. 9.7).

Although muscle fibers and the connective tissues associated with them are flexible, they can tear if overstretched. This type of injury is common in athletes and is called a *muscle strain.* The seriousness of the injury depends on the degree of damage the tissues sustain. In a mild strain, only a few muscle fibers are injured, the fascia remains intact, and little function is lost. In a severe strain, many muscle fibers as well as fascia tear, and muscle function may be lost completely. A severe strain is very painful and is accompanied by discoloration and swelling of tissues due to ruptured blood vessels. Surgery may be required to reconnect the separated tissues.

1 Describe how connective tissue is associated with a skeletal muscle.

2 Describe the general structure of a skeletal muscle fiber.

3 Explain why skeletal muscle fibers appear striated.

4 Explain the physical relationship between the sarcoplasmic reticulum and the transverse tubules.

Skeletal Muscle Contraction

A muscle fiber contraction is a complex interaction of several cellular and chemical constituents. The final result is a movement within the myofibrils in which the filaments of actin and myosin slide past one another, shortening the sarcomeres. When this happens, the muscle fiber shortens and pulls on its attachments.

Actin, myosin, troponin, and tropomyosin are abundant in muscle cells. Scarcer proteins are also vital to muscle function. This is the case for a rod-shaped muscle protein called *dystrophin.* It accounts for only 0.002% of total muscle protein in skeletal muscle, but its absence causes the devastating inherited disorder Duchenne muscular dystrophy, a disease that usually affects boys. Dystrophin binds to the inside face of muscle cell membranes, supporting them against the powerful force of contraction. Without even these minute amounts of dystrophin, muscle cells burst and die. Other forms of muscular dystrophy result from abnormalities of other proteins to which dystrophin attaches.

Neuromuscular Junction

Each skeletal muscle fiber is connected to an extension (a nerve axon) of a **motor neuron** (mo′tor nu′ron) that passes outward from the brain or spinal cord. Normally a skeletal muscle fiber contracts only upon stimulation by a motor neuron.

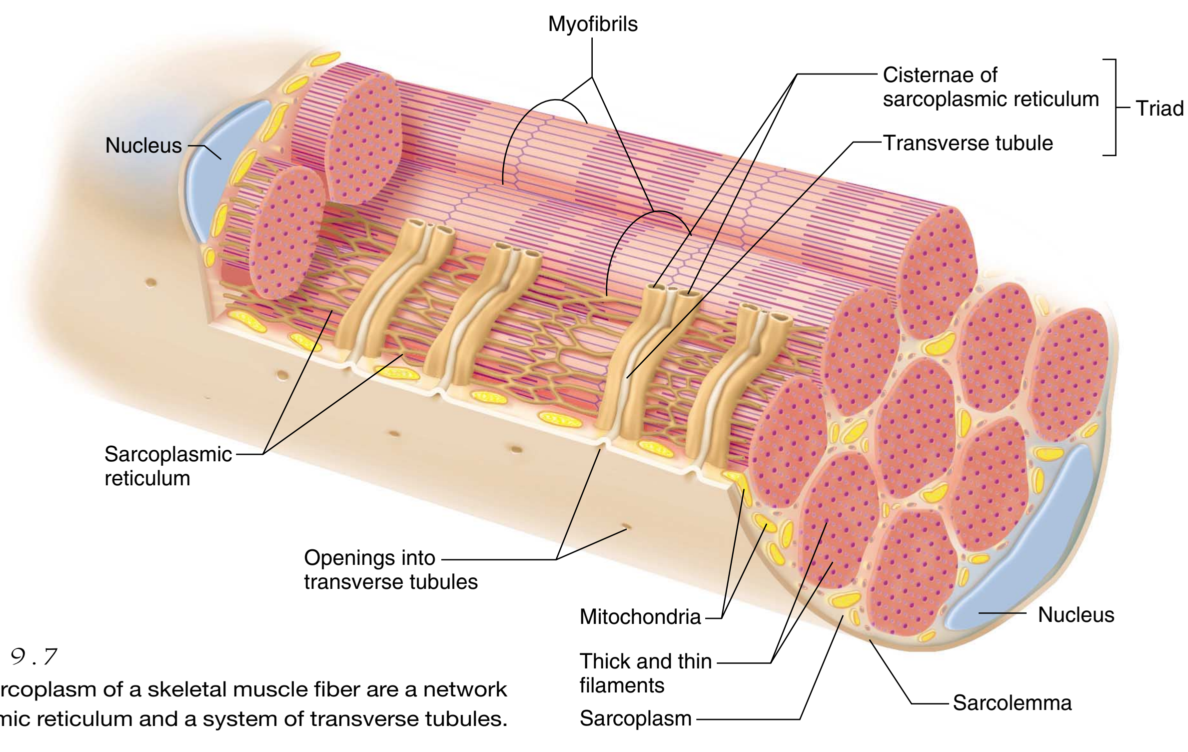


FIGURE 9.7
Within the sarcoplasm of a skeletal muscle fiber are a network of sarcoplasmic reticulum and a system of transverse tubules.

The site where the axon and muscle fiber meet is called a **neuromuscular junction** (myoneural junction). There, the muscle fiber membrane is specialized to form a **motor end plate,** where nuclei and mitochondria are abundant and the sarcolemma is extensively folded (fig. 9.8).

A muscle fiber usually has a single motor end plate. Motor neuron axons, however, are densely branched. By means of these branches, one motor neuron axon may connect to many muscle fibers. Together, a motor neuron and the muscle fibers it controls constitute a **motor unit** (mo′tor u′nit) (fig. 9.9).

In the summer months of the early 1950s, parents in the United States lived in terror of their children contracting poliomyelitis, a viral infection that attacks nerve cells that stimulate skeletal muscles to contract. In half of the millions of affected children, fever, headache, and nausea rapidly progressed to a stiffened back and neck, drowsiness, and then the feared paralysis, usually of the lower limbs or muscles that control breathing or swallowing. Today, many a middle-aged person with a limp owes this slight disability to polio.

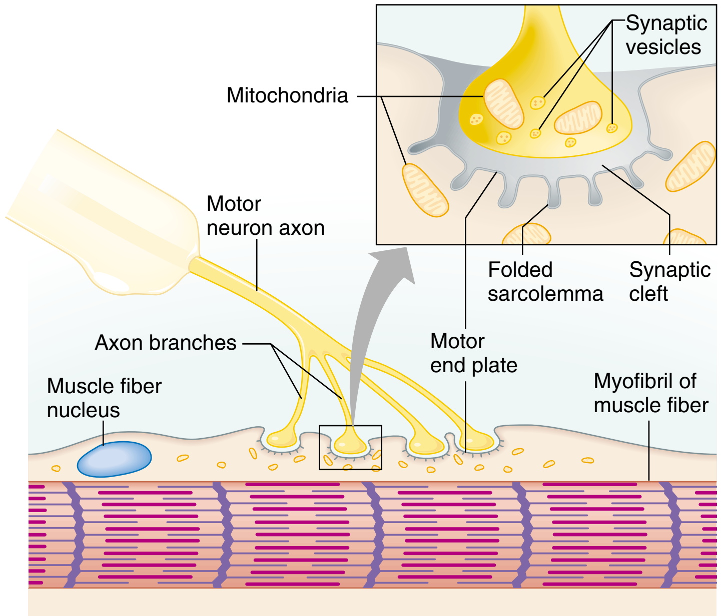
Vaccines introduced in the middle 1950s ended the nightmare of polio in many nations, but the disease has not been globally eradicated because not everyone has been vaccinated. In addition, a third of the 1.6 million polio survivors in the United States are experiencing the fatigue, muscle weakness and atrophy, and difficulty breathing of post-polio syndrome. Researchers think that this condition begins 10 to 40 years after severe poliomyelitis, when surviving motor neurons that grew extra axon branches to compensate for lost neurons degenerate from years of over use. West Nile virus infection causes a poliomyelitis-like syndrome.

A small gap called the **synaptic cleft** separates the membrane of the neuron and the membrane of the muscle fiber**.** The cytoplasm at the distal ends of the nerve fiber is rich in mitochondria and contains many tiny vesicles (synaptic vesicles) that store chemicals called **neurotransmitters** (nu″ro-trans′mit-erz).

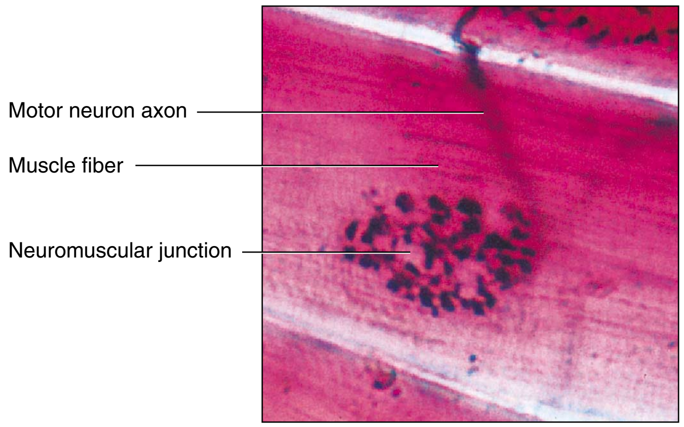
Stimulus for Contraction

Acetylcholine (ACh) is the neurotransmitter that motor neurons use to control skeletal muscle. ACh is synthesized in the cytoplasm of the motor neuron and is stored in synaptic vesicles near the distal end of its axon. When a nerve impulse (or action potential, described in chapter 10, pp. 350–353) reaches the end of the axon, some of these vesicles release acetylcholine into the synaptic cleft (see fig. 9.8).

Acetylcholine diffuses rapidly across the synaptic cleft, combines with ACh receptors on the motor end-plate, and stimulates the muscle fiber. The response is a



(a)



(b)

FIGURE 9.8

Neuromuscular junction. (*a*) A neuromuscular junction includes the end of a motor neuron and the motor end plate of a muscle fiber. (*b*) Micrograph of a neuromuscular junction (500×).

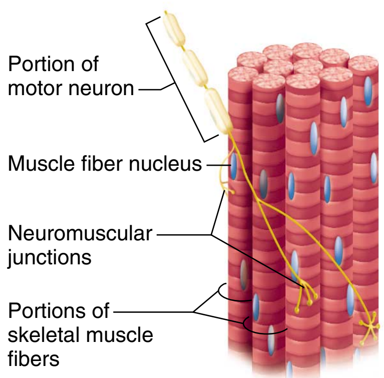


FIGURE 9.9

Muscle fibers within a motor unit may be distributed throughout the muscle.

9.1 CLINICAL APPLICATION

Myasthenia Gravis

In an autoimmune disorder, the immune system attacks part of the body. In myasthenia gravis (MG), that part is the nervous system, particularly receptors for acetylcholine on muscle cells at neuromuscular junctions, where neuron meets muscle cell. People with MG have one-third the normal number of acetylcholine receptors at these junctions. On a whole-body level, this causes weak and easily fatigued muscles.

MG affect hundreds of thousands of people worldwide, usually women, beginning in their twenties or thirties and men in their sixties and seventies. The specific symptoms depend upon the site of attack. For 85% of patients, the disease causes generalized muscle weakness. Many people develop a characteristic flat smile and nasal voice and have difficulty chewing and swallowing due to affected facial and neck muscles. Many have limb weakness. About 15% of patients experience the illness only in the muscles surrounding their eyes. The disease reaches crisis level when respiratory muscles are affected, requiring a ventilator to support breathing. MG does not affect sensation or reflexes.

Until 1958, MG was a serious threat to health, with a third of patients dying, a third worsening, and only a third maintaining or improving their condition. Today, most people with MG can live near-normal lives, thanks to a combination of the following treatments:

- Drugs that inhibit acetylcholinesterase, which boosts availability of acetylcholine.
- Removing the thymus gland, which oversees much of the immune response.
- Immunosuppressant drugs.
- Intravenous antibodies to bind and inactivate the ones causing the damage.
- Plasma exchange, which rapidly removes the damaging antibodies from the circulation. This helps people in crisis. ■

muscle impulse, an electrical signal that is very much like a nerve impulse. A muscle impulse changes the muscle cell membrane in a way that transmits the impulse in all directions along and around the muscle cell, into the transverse tubules, into the sarcoplasm, and ultimately to the sarcoplasmic reticulum and the cisternae. Clinical Application 9.1 discusses myasthenia gravis, in which the immune system attacks certain neuromuscular junctions.

When the bacterium *Clostridium botulinum* grows in an anaerobic (oxygen-poor) environment, such as in a can of unrefrigerated food, it produces a toxin that prevents the release of acetylcholine from nerve terminals if ingested by a person. Symptoms include nausea, vomiting, and diarrhea; headache, dizziness, and blurred or double vision; and finally, weakness, hoarseness, and difficulty swallowing and, eventually, breathing. Physicians can administer an antitoxin substance that binds to and inactivates botulinum toxin in the bloodstream, stemming further symptoms, although not correcting damage already done.

Excitation Contraction Coupling

The sarcoplasmic reticulum has a high concentration of calcium ions compared to the cytosol. This is due to active transport of calcium ions (calcium pump) in the membrane of the sarcoplasmic reticulum. In response to a muscle impulse, the membranes of the cisternae become more permeable to these ions, and the calcium ions diffuse out of the cisternae into the cytosol of the muscle fiber (see fig. 9.7).

RECONNECT TO CHAPTER 3, ACTIVE TRANSPORT, PAGE 85

When a muscle fiber is at rest, the troponin-tropomyosin complexes block the binding sites on the actin molecules and thus prevent the formation of linkages with myosin cross-bridges (fig. 9.10 *1*). As the concentration of calcium ions in the cytosol rises, however, the calcium ions bind to the troponin, changing its shape (conformation) and altering the position of the tropomyosin. The movement of the tropomyosin molecules exposes the binding sites on the actin filaments, allowing linkages to form between myosin cross-bridges and actin (fig. 9.10 *2*).

RECONNECT TO CHAPTER 2, PROTEINS, PAGE 54

The Sliding Filament Theory

The sarcomere is considered the functional unit of skeletal muscles. This is because contraction of an entire skeletal muscle can be described in terms of the shortening of sarcomeres within it. According to the **sliding filament theory,**

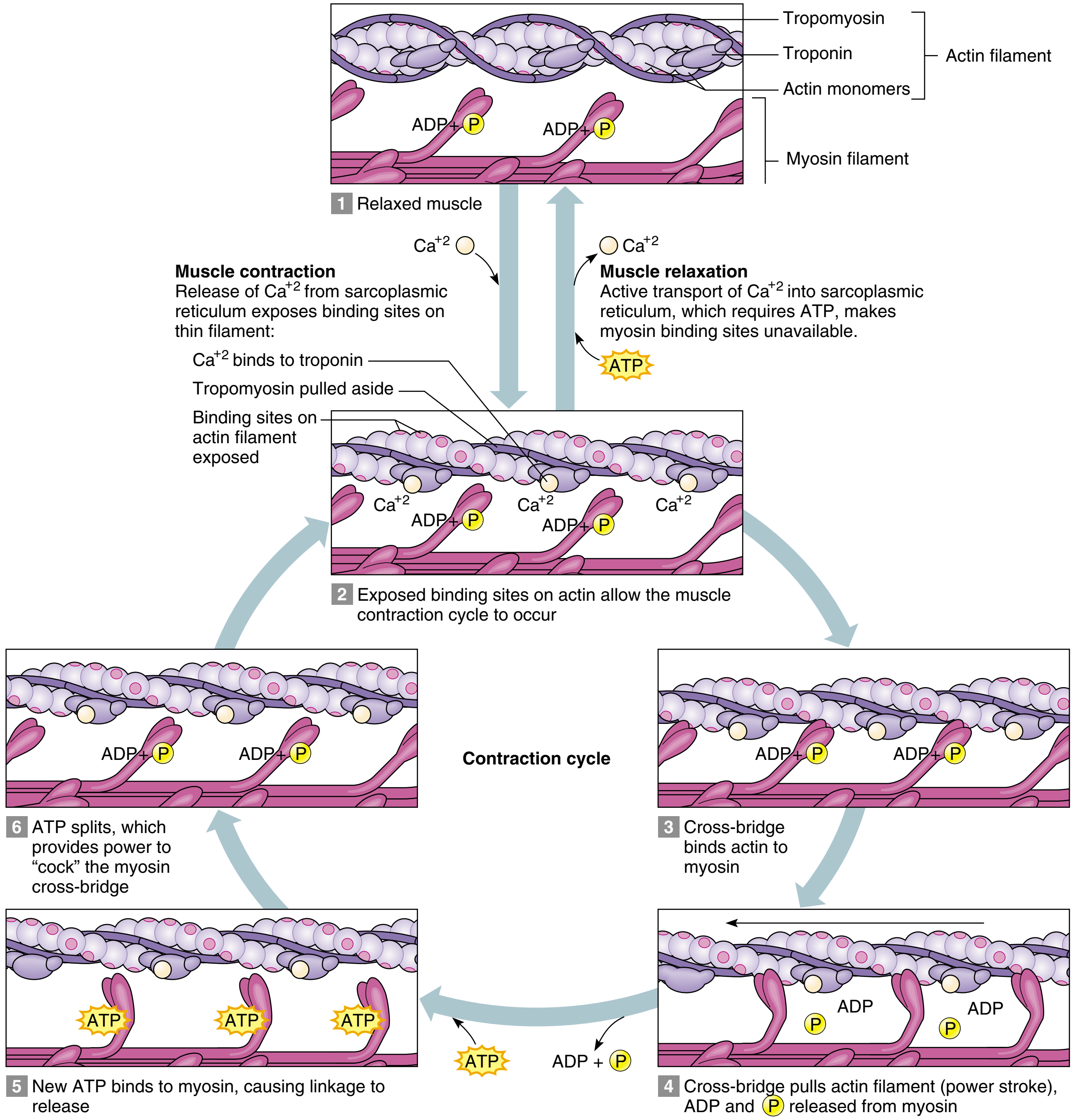


FIGURE 9.10

According to the sliding filament theory (*1–3*) when calcium ion concentration rises, binding sites on actin filaments open, and cross-bridges attach. (*4*) Upon binding to actin, cross-bridges spring from the cocked position and pull on actin filaments. (*5*) ATP binds to the cross-bridge (but is not yet broken down), causing it to release from the actin filament. (*6*) ATP breakdown provides energy to “cock” the unattached myosin cross-bridge. As long as ATP and calcium ions are present, the cycle continues. When calcium ion concentration is low, the muscle remains relaxed.

when sarcomeres shorten, the thick and thin filaments do not themselves change length. Rather, they just slide past one another, with the thin filaments moving toward the center of the sarcomere from both ends. As this occurs, the H zones and the I bands get narrower, the regions of overlap widen, and the Z lines move closer together, shortening the sarcomere (fig. 9.11).

Cross-bridge Cycling

The force that shortens the sarcomeres comes from cross-bridges pulling on the thin filaments. A myosin cross-bridge can attach to an actin binding site and bend slightly, pulling on the actin filament. Then the head can release, straighten, combine with another binding site further down the actin filament, and pull again (see fig. 9.10).

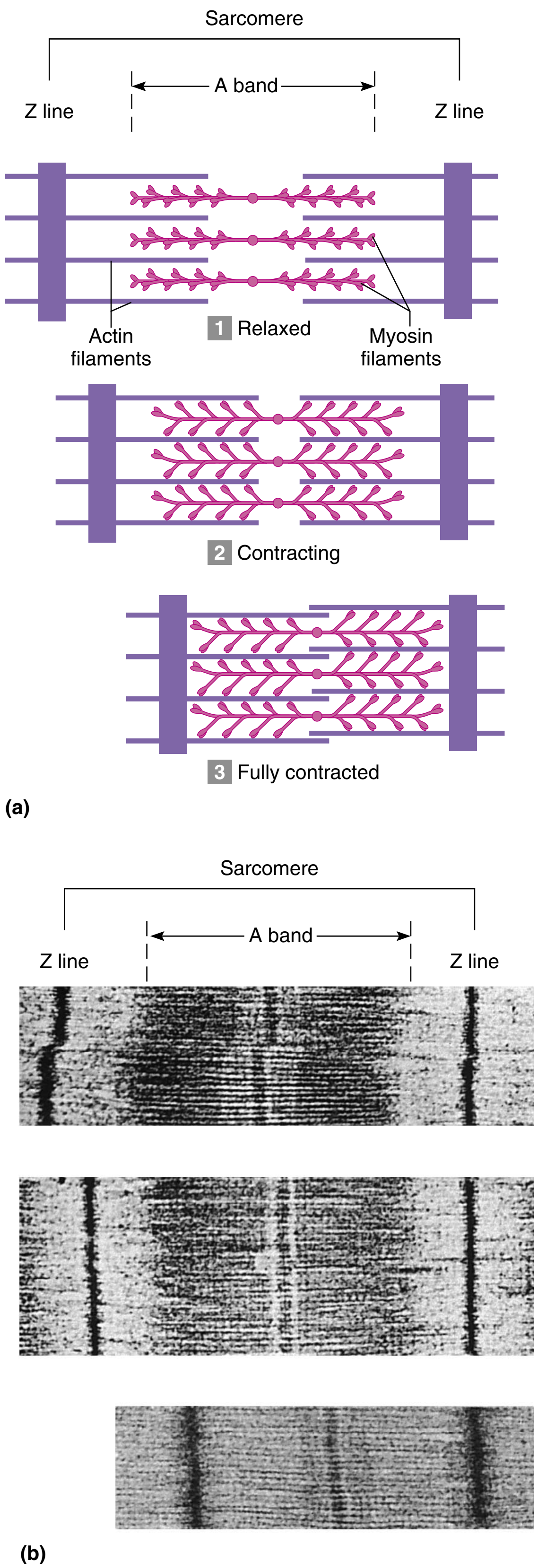


FIGURE 9.11

When a skeletal muscle contracts (*a*), individual sarcomeres shorten as thick and thin filaments slide past one another. (*b*) Transmission electron micrograph showing a sarcomere shortening during muscle contraction (23,000×).

Myosin cross-bridges contain the enzyme **ATPase,** which catalyzes the breakdown of ATP to ADP and phosphate. This reaction releases energy (see chapter 4, p. 000) that provides the force for muscle contraction. Breakdown of ATP puts the myosin cross-bridge in a "cocked" position (fig. 9.10 *6*). When a muscle is stimulated to contract, a cocked cross-bridge attaches to actin (9.10 *3*) and pulls the actin filament toward the center of the sarcomere, shortening the sarcomere and thus shortening the muscle (9.10 *4*). When another ATP binds, the cross-bridge is first released from the actin binding site (9.10 *5*), then breaks down the ATP to return to the cocked position (9.10 *6*). This cross-bridge cycle may repeat over and over, as long as ATP is present and nerve impulses cause ACh release at that neuromuscular junction.

Relaxation

When nerve impulses cease, two events relax the muscle fiber. First, the acetylcholine that remains in the synapse is rapidly decomposed by an enzyme called **acetylcholinesterase.** This enzyme is present in the synapse and on the membranes of the motor end plate. The action of acetylcholinesterase prevents a single nerve impulse from continuously stimulating a muscle fiber.

> If acetylcholine receptors at the motor end plate are too few, or blocked, muscles cannot receive the signal to contract. This may occur as the result of a disease, such as myasthenia gravis, or exposure to a poison, such as nerve gas. A drug called pyridostigmine bromide is used to treat myasthenia gravis. The drug inhibits the enzyme (acetylcholinesterase) that normally breaks down acetylcholine, keeping the neurotransmitter around longer. It was given to veterans of the Persian Gulf War who reported muscle aches in the months following their military service. Health officials reasoned that the drug's effect on myasthenia gravis might also help restore muscle function if the veterans' symptoms arose from exposure to nerve gas during the war. Acetylcholinesterase inhibitors are also used as insecticides. The buildup of acetylcholine causes an insect to twitch violently, then die.

Second, when ACh is broken down, the stimulus to the sarcolemma and the membranes within the muscle fiber ceases. The calcium pump (which requires ATP) quickly moves calcium ions back into the sarcoplasmic reticulum, decreasing the calcium ion concentration of the cytosol. The cross-bridge linkages break (see figure 9.10 *6*—remember, this also requires ATP, although it is not broken down in this step), and tropomyosin rolls back into its groove, preventing any cross-bridge attachment (see fig. 9.10 *1*). Consequently, the muscle fiber relaxes. Table 9.1 summarizes the major events leading to muscle contraction and relaxation.

TABLE 9.1 Major Events of Muscle Contraction and Relaxation	
Muscle Fiber Contraction	**Muscle Fiber Relaxation**
1. The distal end of a motor neuron releases acetylcholine.	**1.** Acetylcholinesterase decomposes acetylcholine, and the muscle fiber membrane is no longer stimulated.
2. Acetylcholine diffuses across the gap at the neuromuscular junction.	**2.** Calcium ions are actively transported into the sarcoplasmic reticulum.
3. The sarcolemma is stimulated, and a muscle impulse travels over the surface of the muscle fiber and deep into the fiber through the transverse tubules and reaches the sarcoplasmic reticulum.	**3.** ATP causes linkages between actin and myosin filaments to break without ATP breakdown.
4. Calcium ions diffuse from the sarcoplasmic reticulum into the sarcoplasm and bind to troponin molecules.	**4.** Cross-bridges recock.
5. Tropomyosin molecules move and expose specific sites on actin filaments.	**5.** Troponin and tropomyosin molecules inhibit the interaction between myosin and actin filaments.
6. Actin and myosin filaments form linkages.	**6.** Muscle fiber remains relaxed, yet ready until stimulated again.
7. Actin filaments are pulled inward by myosin cross-bridges.	
8. Muscle fiber shortens as a contraction occurs.	

It is important to remember that ATP is necessary for both muscle contraction and for muscle relaxation. The trigger for contraction is the increase in cytosolic calcium in response to stimulation by ACh from a motor neuron.

A few hours after death, the skeletal muscles partially contract, fixing the joints. This condition, called *rigor mortis,* may continue for seventy-two hours or more. It results from an increase in membrane permeability to calcium ions, which promotes cross-bridge attachment, and a decrease in availability of ATP in the muscle fibers, which prevents cross-bridge release from actin. Thus, the actin and myosin filaments of the muscle fibers remain linked until the muscles begin to decompose.

1. Describe a neuromuscular junction.
2. Define motor unit.
3. List four proteins associated with myofibrils, and explain their structural and functional relationships.
4. Explain how the filaments of a myofibril interact during muscle contraction.
5. Explain how a motor nerve impulse can trigger a muscle contraction.

Energy Sources for Contraction

The energy used to power the interaction between actin and myosin filaments during muscle fiber contraction comes from ATP molecules. However, a muscle fiber has only enough ATP to contract briefly. Therefore, when a fiber is active, ATP must be regenerated.

The initial source of energy available to regenerate ATP from ADP and phosphate is **creatine phosphate.** Like ATP, creatine phosphate contains a high-energy phosphate bond, and it is actually four to six times more abundant in muscle fibers than ATP. Creatine phosphate, however, cannot directly supply energy to a cell's energy-utilizing reactions. Instead, it stores excess energy released from mitochondria. Thus, whenever sufficient ATP is present, an enzyme in the mitochondria (creatine phosphokinase) promotes the synthesis of creatine phosphate, which stores the excess energy in its phosphate bond (fig. 9.12).

As ATP is decomposed to ADP, the energy from creatine phosphate molecules is transferred to these ADP molecules, quickly converting them back into ATP. The

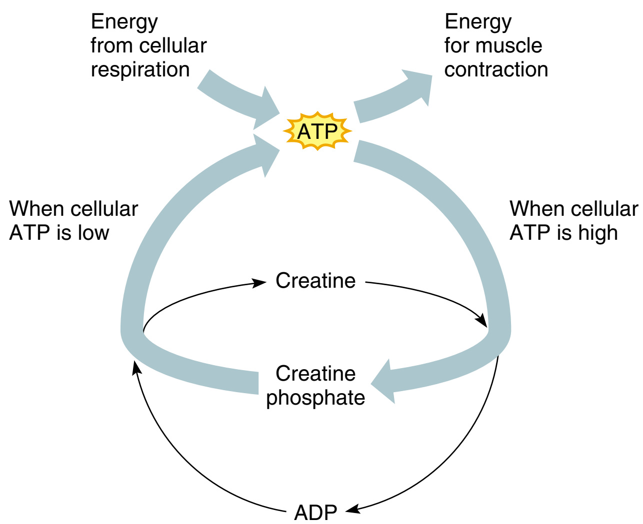


FIGURE 9.12
A muscle cell uses energy released in cellular respiration to synthesize ATP. ATP is then used to power muscle contraction or to synthesize creatine phosphate. Later, creatine phosphate may be used to synthesize ATP.

amount of ATP and creatine phosphate in a skeletal muscle, however, is usually not sufficient to support maximal muscle activity for more than about ten seconds during an intense contraction. As a result, the muscle fibers in an active muscle soon depend upon cellular respiration of glucose as a source of energy for synthesizing ATP. Typically, a muscle stores glucose in the form of glycogen.

Oxygen Supply and Cellular Respiration

Recall from chapter 4 (p. 108) that glycolysis, the early phase of cellular respiration, occurs in the cytoplasm and is *anaerobic,* not dependent on oxygen. This phase only partially breaks down energy-supplying glucose and releases only a few ATP molecules. The complete breakdown of glucose occurs in the mitochondria and is *aerobic,* requiring oxygen. This process, which includes the complex series of reactions of the *citric acid cycle* and *electron transport chain*, produces many ATP molecules.

Blood carries the oxygen necessary to support the aerobic reactions of cellular respiration from the lungs to body cells. Oxygen is transported within the red blood cells loosely bound to molecules of hemoglobin, the pigment responsible for the red color of blood. In regions of the body where the oxygen concentration is relatively low, oxygen is released from hemoglobin and becomes available for the aerobic reactions of cellular respiration.

Another pigment, **myoglobin,** is synthesized in muscle cells and imparts the reddish brown color of skeletal muscle tissue. Like hemoglobin, myoglobin can loosely combine with oxygen and, in fact, has a greater attraction for oxygen than does hemoglobin. Myoglobin can temporarily store oxygen in muscle tissue, which reduces a muscle's requirement for a continuous blood supply during contraction. This oxygen storage is important because blood flow may decrease during muscular contraction when contracting muscle fibers compress blood vessels (fig. 9.13).

Oxygen Debt

When a person is resting or moderately active, the respiratory and cardiovascular systems can usually supply sufficient oxygen to the skeletal muscles to support the aerobic reactions of cellular respiration. However, when skeletal muscles are used more strenuously, these systems may not be able to supply enough oxygen to sustain the aerobic reactions of cellular respiration. The muscle fibers must increasingly utilize the anaerobic reactions of cellular respiration for energy. This can lead to a rapid increase in blood levels of lactic acid, termed the **lactic acid threshold** (anaerobic threshold).

Chapter 4 (p. 108) discussed how under anaerobic conditions, glycolysis breaks glucose down to pyruvic acid and converts it to lactic acid, which diffuses out of

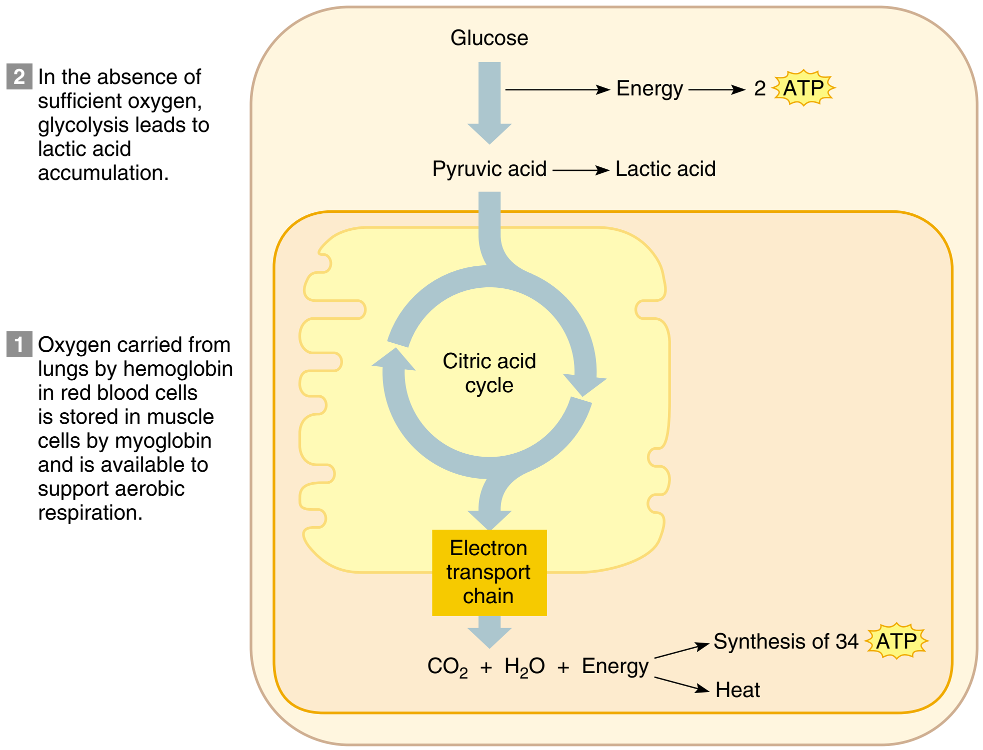


FIGURE 9.13

The oxygen required to support the aerobic reactions of cellular respiration is carried in the blood and stored in myoglobin. In the absence of sufficient oxygen, anaerobic reactions use pyruvic acid to produce lactic acid. The maximum number of ATPs generated per glucose molecule varies with cell type; in skeletal muscle, it is 36 (2 + 34).

the muscle fibers and is carried in the bloodstream to the liver. Liver cells can react lactic acid to form *glucose,* but this requires energy from ATP (fig. 9.14). During strenuous exercise, available oxygen is primarily used to synthesize ATP for muscle contraction rather than to make ATP for converting lactic acid into glucose. Consequently, as lactic acid accumulates, a person develops an **oxygen debt** that must be repaid at a later time. The amount of oxygen debt roughly equals the amount of oxygen liver cells require to convert the accumulated lactic acid into glucose, plus the amount the muscle cells require to resynthesize ATP and creatine phosphate, and restore their original concentrations. It also reflects the oxygen needed to restore blood and tissue oxygen levels to preexercise levels.

The metabolic capacity of a muscle may change with training. Thus, with high-intensity exercise that depends more on glycolysis for ATP, a muscle will synthesize more glycolytic enzymes, and its capacity for glycolysis will increase. With aerobic exercise, more capillaries and mitochondria will appear, and the muscles' capacity for the aerobic reactions of cellular respiration is greater.

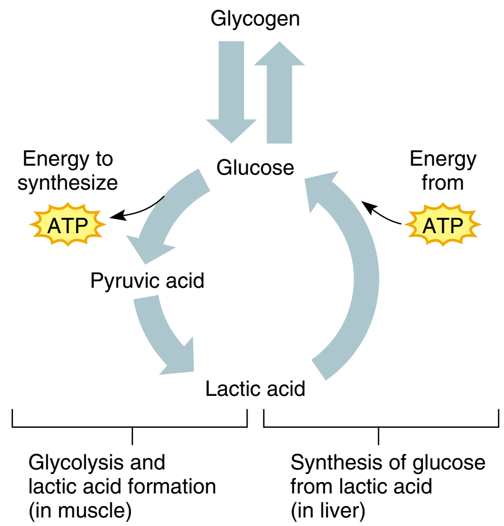


FIGURE 9.14

Liver cells can convert lactic acid, generated by muscles anaerobically, to glucose.

> The runners are on the starting line, their muscles primed for a sprint. Glycogen will be broken down to release glucose, and creatine phosphate will supply high-energy phosphate groups to replenish ATP stores by phosphorylating ADP. The starting gun fires. Energy comes first from residual ATP, but almost instantaneously, creatine phosphate begins donating high-energy phosphates to ADP, regenerating ATP. Meanwhile, oxidation of glucose ultimately produces more ATP. But because the runner cannot take in enough oxygen to meet the high demand, most ATP is generated in glycolysis. Formation of lactic acid causes fatigue and possibly leg muscle cramps as the runner crosses the finish line. Already, her liver is actively converting lactic acid back to pyruvic acid and storing glycogen. In her muscles, creatine phosphate begins to build again.

Muscle Fatigue

A muscle exercised persistently for a prolonged period may lose its ability to contract, a condition called *fatigue.* This condition may result from a number of causes, including decreased blood flow, ion imbalances across the sarcolemma resulting from repeated stimulation, and psychological loss of the desire to continue the exercise. However, muscle fatigue is most likely to arise from accumulation of lactic acid in the muscle as a result of anaerobic ATP production. The lowered pH from the lactic acid prevents muscle fibers from responding to stimulation.

Occasionally a muscle fatigues and cramps at the same time. A cramp is a painful condition in which a muscle undergoes a sustained, involuntary contraction. Cramps are thought to occur when changes in the extracellular fluid, particularly a decreased electrolyte concentration, surrounding the muscle fibers and their motor neurons somehow trigger uncontrolled stimulation of the muscle.

As muscle metabolism shifts from aerobic ATP production to anaerobic ATP production, lactic acid begins to accumulate in muscles and to appear in the bloodstream (lactic acid threshold). This leads to muscle fatigue. How quickly this happens varies from individual to individual, although people who regularly exercise aerobically produce less lactic acid than those who do not. Physically fit people make less lactic acid, because the strenuous exercise of aerobic training stimulates new capillaries to grow within the muscles, supplying more oxygen and nutrients to the muscle fibers. Such physical training also causes muscle fibers to produce additional mitochondria, increasing their ability to carry on the aerobic reactions of cellular respiration. Some muscle fibers may be more likely to accumulate lactic acid than others, as described in the section titled "Fast and Slow Muscle Fibers."

Heat Production

Heat is a by-product of cellular respiration; all active cells generate heat. Since muscle tissue represents such a large proportion of the total body mass, it is a major source of heat.

Less than half of the energy released in cellular respiration is available for use in metabolic processes; the rest becomes heat. Active muscles release a great deal of heat. Blood transports this heat throughout the body, which helps to maintain body temperature. Homeostatic mechanisms promote heat loss when the temperature of the internal environment begins to rise (see chapters 1 and 6, pp. 10–11 and 170, respectively).

1. What are the sources of energy used to regenerate ATP?
2. What are the sources of oxygen required for the aerobic reactions of cellular respiration?
3. How do lactic acid and oxygen debt relate to muscle fatigue?
4. What is the relationship between cellular respiration and heat production?

Muscular Responses

One way to observe muscle contraction is to remove a single muscle fiber from a skeletal muscle and connect it to a device that senses and records changes in the fiber's length. An electrical stimulator is usually used to promote muscle contraction.

Threshold Stimulus

When an isolated muscle fiber is exposed to a series of stimuli of increasing strength, the fiber remains unresponsive until a certain strength of stimulation is applied. This minimal strength required to cause contraction is called the **threshold stimulus** (thresh′old stim′u-lus). An impulse in a motor neuron normally releases enough ACh to bring the muscle fibers in its motor unit to threshold.

Recording a Muscle Contraction

The response of a single muscle fiber to the ACh released by a single action potential is called a **twitch.** A twitch involves a *period of contraction,* when the fiber pulls at its attachments, followed by a *period of relaxation,* during which pulling force declines. These events can be recorded, and the resulting pattern is called a **myogram** (fig. 9.15). Note that a twitch has a brief delay between the time of stimulation and the beginning of contraction. This is the **latent period,** which in human muscle may be less than 0.01 seconds.

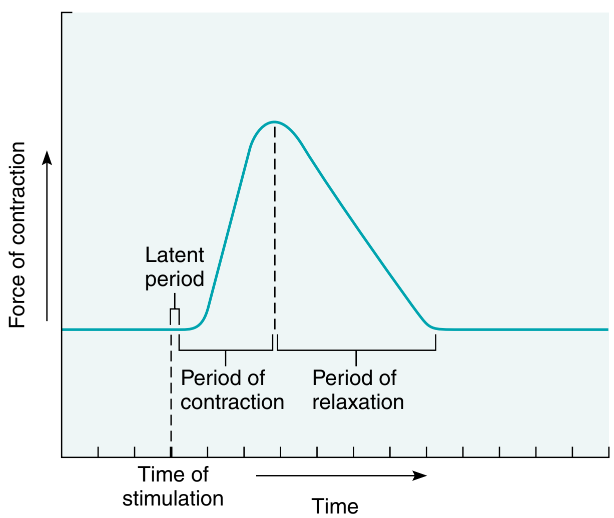


FIGURE 9.15
A myogram of a single muscle twitch.

If a muscle fiber is exposed to two stimuli (of threshold strength or greater) too quickly, it may respond with a twitch to the first stimulus but not to the second. This is because it takes an instant following a contraction for muscle fibers to become responsive to further stimulation. Thus, for a very brief moment following stimulation, a muscle fiber remains unresponsive. This time is called the **refractory period.**

A resting muscle fiber that is not brought to threshold will not contract. If a threshold strength or above stimulus is applied to a resting muscle fiber, enough calcium ions are released from the sarcoplasmic reticulum to fully activate cross-bridge binding. The actual force generated by that fiber depends on its length when stimulated, but at any given length, it will either contract or not. This has been termed the **all-or-none response.**

The length to which a muscle is stretched before stimulation affects the force it will develop when stimulated. If a muscle is stretched well beyond its normal resting length, the force will decrease. This is because sarcomeres become so long that myosin cross-bridges cannot reach binding sites on the thin filaments and cannot participate in contraction. Conversely, at very short muscle lengths, the sarcomere becomes compressed, and further shortening is not possible. During normal activities, muscles contract at their optimal lengths. Some activities, such as walking up stairs two steps at a time or lifting something from an awkward position, put muscles at a disadvantageous length and compromise performance.

To record how a whole muscle responds to stimulation, a skeletal muscle can be removed from a frog or other small animal and mounted in a special device. The muscle is then stimulated electrically, and when it contracts, it pulls on a lever. The lever's movement is recorded as a myogram. Because the myogram results from the combined twitches of muscle fibers taking part in the contraction, it looks essentially the same as the twitch contraction depicted in figure 9.15.

Twitch contractions are of little importance; rather, sustained contractions of whole muscles enable us to perform everyday activities. In the whole muscle, the degree of tension developed reflects (1) the frequency at which individual fibers are stimulated and (2) how many fibers take part in the overall contraction of the muscle.

Summation

The force that a muscle fiber can generate is not limited to the maximum force of a single twitch (fig. 9.16*a*). A muscle fiber exposed to a series of stimuli of increasing frequency reaches a point when it is unable to completely relax before the next stimulus in the series arrives. When this happens, the individual twitches begin to combine, and the muscle contraction becomes sustained. In such a

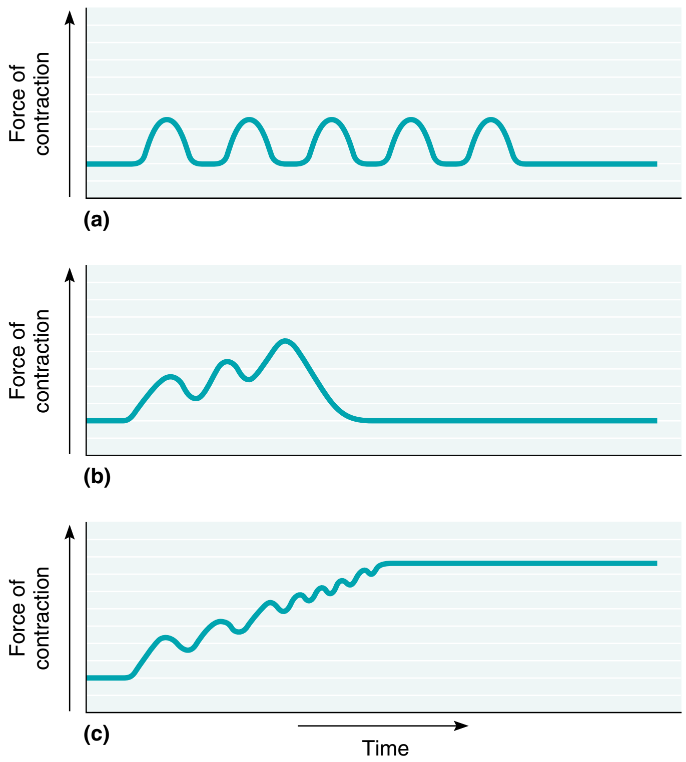


FIGURE 9.16
Myograms of (*a*) a series of twitches, (*b*) summation, and (*c*) a tetanic contraction. Note that stimulation frequency increases from one myogram to the next.

sustained contraction, the force of individual twitches combines by the process of **summation** (fig. 9.16*b*). When the resulting forceful, sustained contraction lacks even partial relaxation, it is called a **tetanic** (te-tan-ik) **contraction** (tetanus) (fig. 9.16*c*).

Recruitment of Motor Units

The number of muscle fibers in a motor unit varies considerably. The fewer muscle fibers in the motor units, however, the more precise the movements that can be produced in a particular muscle. For example, the motor units of the muscles that move the eyes may contain fewer than ten muscle fibers per motor unit and can produce very slight movements. Conversely, the motor units of the large muscles in the back may include a hundred or more muscle fibers. When these motor units are stimulated, the movements that result are less gradual compared to those of the eye.

Since the muscle fibers within a muscle are organized into motor units and each motor unit is controlled by a single motor neuron, all the muscle fibers in a motor unit are stimulated at the same time. Therefore, a motor unit also responds in an all-or-none manner. A whole muscle, however, does not behave like this, because it is composed of many motor units controlled by different motor neurons, some of which are more easily stimulated than others. Thus, if only the more easily stimulated motor neurons are involved, few motor units contract. At higher intensities of stimulation, other motor neurons respond, and more motor units are activated. Such an increase in the number of activated motor units is called *multiple motor unit summation,* or **recruitment** (re-kr$\overline{oo}$t′ ment). As the intensity of stimulation increases, recruitment of motor units continues until finally all possible motor units are activated in that muscle.

Sustained Contractions

During sustained contractions, smaller motor units, which have smaller diameter axons, tend to be recruited earlier. The larger motor units, which contain larger diameter axons, respond later and more forcefully. The product is a sustained contraction of increasing strength.

Typically, many action potentials are triggered in a motor neuron when it is called into action, thus individual twitches do not normally occur. Tetanic contractions of muscle fibers are common. On the whole-muscle level, contractions are smooth rather than irregular or jerky because the spinal cord stimulates contractions in different sets of motor units at different moments.

Tetanic contractions occur frequently in skeletal muscles during everyday activities. In many cases, the condition occurs in only a portion of a muscle. For example, when a person lifts a weight or walks, sustained contractions are maintained in the upper limb or lower limb muscles for varying lengths of time. These contractions are responses to a rapid series of stimuli transmitted from the brain and spinal cord on motor neurons.

Even when a muscle appears to be at rest, a certain amount of sustained contraction is occurring in its fibers. This is called **muscle tone** (tonus), and it is a response to nerve impulses originating repeatedly in the spinal cord and traveling to a few muscle fibers. The result is a continuous state of partial contraction.

Muscle tone is particularly important in maintaining posture. Tautness in the muscles of the neck, trunk, and lower limbs enables a person to hold the head upright, stand, or sit. If tone is suddenly lost, such as when a person loses consciousness, the body will collapse. Muscle tone is maintained in health but is lost if motor nerve axons are cut or if diseases interfere with conduction of nerve impulses.

When skeletal muscles are contracted very forcefully, they may generate up to 50 pounds of pull for each square inch of muscle cross section. Consequently, large muscles such as those in the thigh can pull with several hundred pounds of force. Occasionally, this force is so great that the tendons of muscles tear away from their attachments to the bones.

Types of Contractions

Sometimes muscles shorten when they contract. For example, if a person lifts an object, the muscles remain taut, their attached ends pull closer together, and the object is moved. This type of contraction is termed **isotonic** (equal force—change in length), and because shortening occurs, it is called **concentric.**

Another type of isotonic contraction, called a lengthening or an **eccentric contraction,** occurs when the force a muscle generates is less than that required to move or lift an object, as in laying a book down on a table. Even in such a contraction, cross-bridges are working but not generating enough force to shorten the muscle.

At other times, a skeletal muscle contracts, but the parts to which it is attached do not move. This happens, for instance, when a person pushes against a wall. Tension within the muscles increases, but the wall does not move, and the muscles remain the same length. Contractions of this type are called **isometric** (equal length—change in force). Isometric contractions occur continuously in postural muscles that stabilize skeletal parts and hold the body upright. Figure 9.17 illustrates isotonic and isometric contractions.

Most body actions involve both isotonic and isometric contraction. In walking, for instance, certain leg and thigh muscles contract isometrically and keep the limb stiff as it touches the ground, while other muscles contract isotonically, bending the limb and lifting it. Similarly, walking down stairs involves eccentric contraction of certain thigh muscles.

Fast and Slow Twitch Muscle Fibers

Muscle fibers vary in contraction speed (slow twitch or fast twitch) and in whether they produce ATP oxidatively or glycolytically. Three combinations of these characteristics are found in humans. Slow-twitch fibers (type I) are always oxidative and are therefore resistant to fatigue. Fast-twitch fibers (type II) may be primarily glycolytic (fatigable) or primarily oxidative (fatigue resistant).

Slow-twitch (type I) fibers, such as those found in the long muscles of the back, are often called *red fibers* because they contain the red, oxygen-storing pigment myoglobin. These fibers are well supplied with oxygen-carrying blood. In addition, red fibers contain many mitochondria, an adaptation for the aerobic reactions of cellular respiration. These fibers have a high respiratory capacity and can generate ATP fast enough to keep up with the ATP breakdown that occurs when they contract. For this reason, these fibers can contract for long periods without fatiguing.

Fast-twitch glycolytic fibers (type IIa) are often called *white fibers* because they contain less myoglobin and have a poorer blood supply than red fibers. They include fibers found in certain hand muscles as well as in muscles that move the eye. These fibers have fewer mitochondria and thus have a reduced respiratory capacity. However, they have a more extensive sarcoplasmic reticulum to store and reabsorb calcium ions, and their ATPase is faster than that of red fibers. Because of these factors, white muscle fibers can contract rapidly, although they tend to fatigue as lactic acid accumulates and as the ATP and the biochemicals to regenerate ATP are depleted.

A third kind of fiber, the fast-twitch fatigue-resistant fibers (type IIb), are sometimes called *intermediate fibers*. These fibers have the fast-twitch speed associated with white fibers combined with a substantial oxidative capacity more characteristic of red fibers.

While some muscles may have mostly one fiber type or another, all muscles contain a combination of fiber types. The speed of contraction and aerobic capacities of the fibers present reflect the specialized functions of the muscle. For example, muscles that move the eyes contract about ten times faster than those that maintain posture,

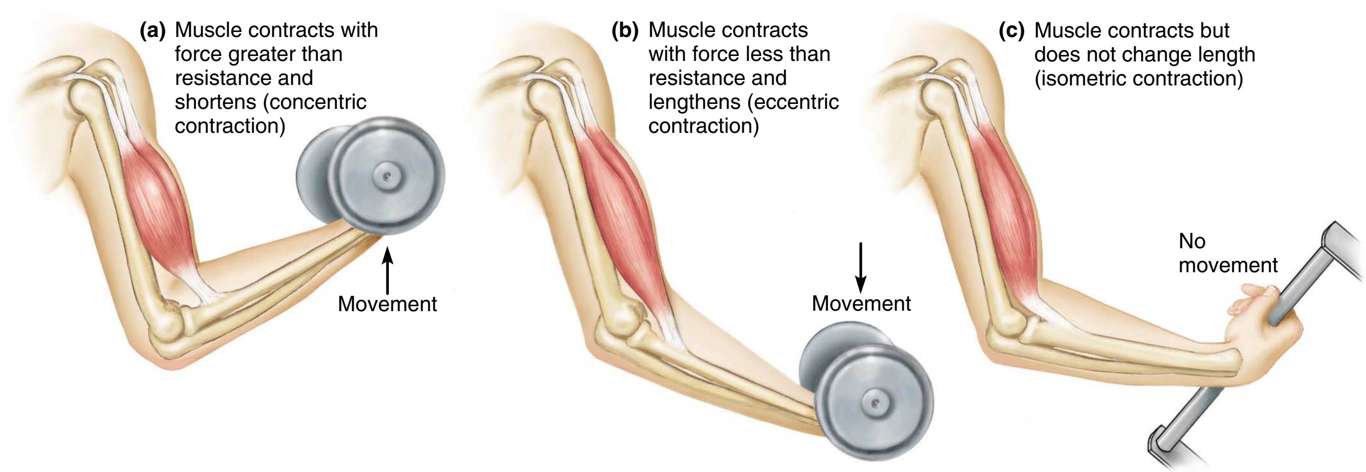


FIGURE 9.17

Types of muscle contractions. (*a* and *b*) Isotonic contractions include concentric and eccentric contractions. (*c*) Isometric contractions occur when a muscle contracts but does not shorten.

9.2 CLINICAL APPLICATION

Use and Disuse of Skeletal Muscles

Skeletal muscles are very responsive to use and disuse. Those that are forcefully exercised tend to enlarge. This phenomenon is called *muscular hypertrophy.* Conversely, a muscle that is not used *atrophies*—it decreases in size and strength.

The way a muscle responds to use also depends on the type of exercise. For instance, when a muscle contracts weakly, as during swimming and running, its slow, fatigue-resistant red fibers are most likely to be activated. As a result, these fibers develop more mitochondria and more extensive capillary networks. Such changes increase the fibers' abilities to resist fatigue during prolonged exercise, although their sizes and strengths may remain unchanged.

Forceful exercise, such as weightlifting, in which a muscle exerts more than 75% of its maximum tension, uses the muscle's fast, fatigable white fibers. In response, existing muscle fibers develop new filaments of actin and myosin, and as their diameters increase, the entire muscle enlarges. However, no new muscle fibers are produced during hypertrophy.

Since the strength of a contraction is directly proportional to the diameter of the muscle fibers, an enlarged muscle can contract more strongly than before. However, such a change does not increase the muscle's ability to resist fatigue during activities such as running or swimming.

If regular exercise stops, capillary networks shrink, and the number of mitochondria within the muscle fibers fall. Actin and myosin filaments diminish, and the entire muscle atrophies. Injured limbs immobilized in casts, or accidents or diseases that interfere with motor nerve impulses, commonly cause muscle atrophy. A muscle that cannot be exercised may shrink to less than one-half its usual size within a few months.

Muscle fibers whose motor neurons are severed not only shrink but also may fragment and, in time, be replaced by fat or fibrous tissue. However, reinnervation of such a muscle within the first few months following an injury can restore function. ■

and the muscles that move the limbs contract at intermediate rates. Clinical Application 9.2 discusses very noticeable effects of muscle use and disuse.

Birds that migrate long distances have abundant dark, slow-twitch muscles—this is why their meat is dark. In contrast, chickens that can only flap around the barnyard have abundant fast-twitch muscles, and mostly white meat.

World-class distance runners are the human equivalent of the migrating bird. Their muscles may contain over 90% slow-twitch fibers! In some European nations, athletic coaches measure slow-twitch to fast-twitch muscle fiber ratios to predict who will excel at long-distance events and who will fare better in sprints.

1. Define *threshold stimulus.*
2. What is an all-or-none response?
3. Distinguish between a twitch and a sustained contraction.
4. Define *muscle tone.*
5. Explain the differences between isometric and isotonic contractions.
6. Distinguish between fast-contracting and slow-contracting muscles fibers.

Smooth Muscles

The contractile mechanisms of smooth and cardiac muscles are essentially the same as those of skeletal muscles. However, the cells of these tissues have important structural and functional differences.

Smooth Muscle Fibers

As discussed in chapter 5 (p. 150), smooth muscle cells are shorter than the fibers of skeletal muscle, and they have single, centrally located nuclei. Smooth muscle cells are elongated with tapering ends and contain filaments of actin and myosin in myofibrils that extend throughout their lengths. However, the filaments are very thin and more randomly organized than those in skeletal muscle fibers. As a result, smooth muscle cells lack striations. They also lack transverse tubules, and their sarcoplasmic reticula are not well developed.

The two major types of smooth muscles are multiunit and visceral. In **multiunit smooth muscle,** the muscle fibers are less well organized and function as separate units, independent of neighboring cells. Smooth muscle of this type is found in the irises of the eyes and in the walls of blood vessels. Typically, multiunit smooth muscle contracts only after stimulation by motor nerve impulses or certain hormones.

Visceral smooth muscle (single-unit smooth muscle) is composed of sheets of spindle-shaped cells held

in close contact by gap junctions. The thick portion of each cell lies next to the thin parts of adjacent cells. Fibers of visceral smooth muscle respond as a single unit. When one fiber is stimulated, the impulse moving over its surface may excite adjacent fibers that, in turn, stimulate others. Some visceral smooth muscle cells also display *rhythmicity*—a pattern of spontaneous repeated contractions.

These two features of visceral smooth muscle—transmission of impulses from cell to cell and rhythmicity—are largely responsible for the wavelike motion called **peristalsis** that occurs in certain tubular organs (see chapter 17, p. 000). Peristalsis consists of alternate contractions and relaxations of the longitudinal and circular muscles. These movements help force the contents of a tube along its length. In the intestines, for example, peristaltic waves move masses of partially digested food and help to mix them with digestive fluids. Peristalsis in the ureters moves urine from the kidneys to the urinary bladder.

Visceral smooth muscle is the more common type of smooth muscle and is found in the walls of hollow organs, such as the stomach, intestines, urinary bladder, and uterus. Usually there are two thickness of smooth muscle in the walls of these organs. The fibers of the outer coats are directed longitudinally, whereas those of the inner coats are arranged circularly. These muscular layers change the sizes and shapes of these organs as they function.

Smooth Muscle Contraction

Smooth muscle contraction resembles skeletal muscle contraction in a number of ways. Both mechanisms reflect reactions of actin and myosin; both are triggered by membrane impulses and release of calcium ions; and both use energy from ATP molecules. There are, however, significant differences between smooth and skeletal muscle action. For example, smooth muscle fibers lack troponin, the protein that binds to calcium ions in skeletal muscle. Instead, smooth muscle uses a protein called *calmodulin,* which binds to calcium ions released when its fibers are stimulated, thus activating the actin-myosin contraction mechanism. In addition, much of the calcium necessary for smooth muscle contraction diffuses into the cell from the extracellular fluid.

Acetylcholine, the neurotransmitter in skeletal muscle, as well as *norepinephrine,* affect smooth muscle. Each of these neurotransmitters stimulates contractions in some smooth muscles and inhibits contractions in others. The discussion of the autonomic nervous system in chapter 11 (p. 000) describes these actions in greater detail.

Hormones affect smooth muscles by stimulating or inhibiting contraction in some cases and altering the degree of response to neurotransmitters in others. For example, during the later stages of childbirth, the hormone oxytocin stimulates smooth muscles in the wall of the uterus to contract (see chapter 22, p. 000).

Stretching of smooth muscle fibers can also trigger contractions. This response is particularly important to the function of visceral smooth muscle in the walls of certain hollow organs, such as the urinary bladder and the intestines. For example, when partially digested food stretches the wall of the intestine, automatic contractions move the contents away.

Smooth muscle is slower to contract and slower to relax than skeletal muscle. On the other hand, smooth muscle can forcefully contract longer with the same amount of ATP. Unlike skeletal muscle, smooth muscle fibers can change length without changing tautness; because of this, smooth muscles in the stomach and intestinal walls can stretch as these organs fill, holding the pressure inside the organs constant.

1. Describe the two major types of smooth muscle.
2. What special characteristics of visceral smooth muscle make peristalsis possible?
3. How is smooth muscle contraction similar to skeletal muscle contraction?
4. How do the contraction mechanisms of smooth and skeletal muscles differ?

Cardiac Muscle

Cardiac muscle appears only in the heart. It is composed of striated cells joined end to end, forming fibers that are interconnected in branching, three-dimensional networks. Each cell contains a single nucleus and many filaments of actin and myosin similar to those in skeletal muscle. A cardiac muscle cell also has a well-developed sarcoplasmic reticulum, a system of transverse tubules, and many mitochondria. However, the cisternae of the sarcoplasmic reticulum of a cardiac muscle fiber are less developed and store less calcium than those of a skeletal muscle fiber. On the other hand, the transverse tubules of cardiac muscle fibers are larger than those in skeletal muscle, and they release many calcium ions into the sarcoplasm in response to a single muscle impulse.

The calcium ions in transverse tubules come from the fluid outside the muscle fiber. Thus, extracellular calcium partially controls the strength of cardiac muscle contraction and enables cardiac muscle fibers to contract longer than skeletal muscle fibers can.

Drugs called calcium channel blockers are used to stop spasms of the heart muscle. They do this by blocking ion channels that admit extracellular calcium into cardiac muscle cells.

The opposing ends of cardiac muscle cells are connected by cross-bands called *intercalated discs.* These bands are actually complex membrane junctions. Not only do they help join cells and transmit the force of contraction from cell to cell, but the intercellular junctions of the fused membranes of intercalated discs allow ions to diffuse between the cells. This allows muscle impulses to travel rapidly from cell to cell (see figs. 5.30 and 9.18).

When one portion of the cardiac muscle network is stimulated, the impulse passes to other fibers of the network, and the whole structure contracts as a unit (a *syncytium*); that is, the network responds to stimulation in an all-or-none manner. Cardiac muscle is also self-exciting and rhythmic. Consequently, a pattern of contraction and relaxation repeats again and again, causing the rhythmic contraction of the heart. Also, the refractory period of cardiac muscle is longer than in skeletal muscle and lasts until the contraction ends. Thus, sustained or tetanic contractions do not occur in the heart muscle. Table 9.2 summarizes characteristics of the three types of muscles.

FIGURE 9.18
The intercalated discs of cardiac muscle, shown in this transmission electron micrograph, bind adjacent cells and allow ions to move between cells (12,500×).

TABLE 9.2 Characteristics of Muscle Tissues

	Skeletal	**Smooth**	**Cardiac**
Dimensions			
Length	Up to 30 cm	30–200 μm	50–100 μm
Diameter	10–100 μm	3–6 μm	14 μm
Major location	Skeletal muscles	Walls of hollow organs	Wall of the heart
Major function	Movement of bones at joints; maintenance of posture	Movement of walls of hollow organs; peristalsis; vasoconstriction	Pumping action of the heart
Cellular characteristics			
Striations	Present	Absent	Present
Nucleus	Multiple nuclei	Single nucleus	Single nucleus
Special features	Transverse tubule system is well developed	Lacks transverse tubules	Transverse tubule system is well developed; intercalated discs separate cells
Mode of control	Voluntary	Involuntary	Involuntary
Contraction characteristics	Contracts and relaxes relatively rapidly	Contracts and relaxes relatively slowly; some types self-exciting; rhythmic	Network of fibers contracts as a unit; self-exciting; rhythmic; remains refractory until contraction ends

1 How is cardiac muscle similar to skeletal muscle?

2 How does cardiac muscle differ from skeletal muscle?

3 What is the function of intercalated discs?

4 What characteristic of cardiac muscle causes the heart to contract as a unit?

Skeletal Muscle Actions

Skeletal muscles generate a great variety of body movements. The action of each muscle mostly depends upon the kind of joint it is associated with and the way the muscle is attached on either side of that joint.

Origin and Insertion

Recall from chapter 8 (p. 261) that one end of a skeletal muscle is usually fastened to a relatively immovable or fixed part, and the other end is connected to a movable part on the other side of a joint. The immovable end is called the **origin** of the muscle, and the movable end is called its **insertion.** When a muscle contracts, its insertion is pulled toward its origin (fig. 9.19). The head of a muscle is the part nearest its origin.

Some muscles have more than one origin or insertion. The *biceps brachii* in the arm, for example, has two origins. This is reflected in its name *biceps,* meaning "two heads." As figure 9.19 shows, one head of the muscle is attached to the coracoid process of the scapula, and the other head arises from a tubercle above the glenoid cavity of the scapula. The muscle extends along the anterior surface of the humerus and is inserted by a single tendon on the radial tuberosity of the radius. When the biceps brachii contracts, its insertion is pulled toward its origin, and the elbow bends.

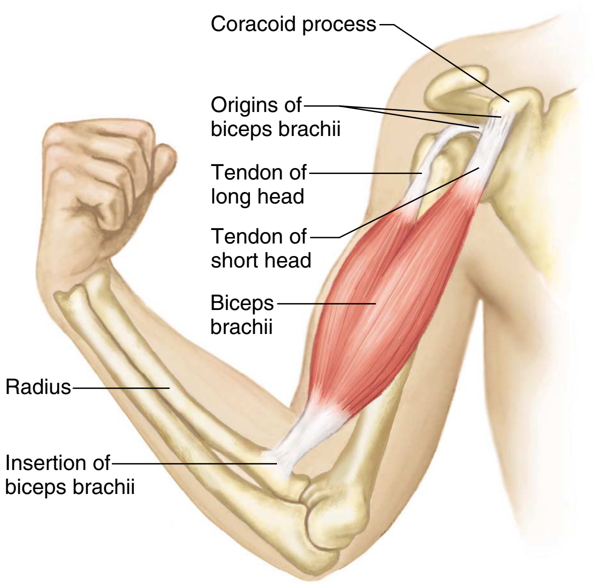


FIGURE 9.19
The biceps brachii has two heads that originate on the scapula. A tendon inserts this muscle on the radius.

Interaction of Skeletal Muscles

Skeletal muscles almost always function in groups. As a result, when a particular body part moves, a person must do more than contract a single muscle; instead, after learning to make a particular movement, the person wills the movement to occur, and the nervous system stimulates the appropriate group of muscles.

By carefully observing body movements, it is possible to determine the roles of particular muscles. For instance, abduction of the arm requires contracting the *deltoid* muscle, which is said to be the **prime mover** or **agonist.** A prime mover is the muscle primarily responsible for producing an action. However, while a prime mover is acting, certain nearby muscles also contract. When a deltoid muscle contracts, nearby muscles help hold the shoulder steady and in this way make the action of the prime mover more effective. Muscles that contract and assist a prime mover are called **synergists** (sin′er-jists).

Still other muscles act as **antagonists** (an-tag′o-nists) to prime movers. These muscles can resist a prime mover's action and cause movement in the opposite direction—the antagonist of the prime mover that raises the upper limb can lower the upper limb, or the antagonist of the prime mover that bends the upper limb can straighten it. If both a prime mover and its antagonist contract simultaneously, the structure they act upon remains rigid. Similarly, smooth body movements depend upon the antagonists' relaxing and giving way to the prime movers whenever the prime movers contract. Once again, the nervous system controls these complex actions, as described in chapter 11 (p. 000).

The movements termed "flexion" and "extension" describe changes in the angle between bones that meet at a joint. For example, flexion of the elbow joint refers to a movement of the forearm that decreases the angle at the elbow joint. Alternatively, one could say that flexion at the elbow results from the action of the biceps brachii on the radius of the forearm.

Since students often find it helpful to think of movements in terms of the specific actions of the muscles involved, we may also describe flexion and extension in these terms. Thus, the action of the biceps brachii may be described as "flexion of the forearm at the elbow" and the action of the quadriceps group as "extension of the leg at the knee." We believe that this occasional departure from strict anatomical terminology eases understanding and learning.

1 Distinguish between the origin and the insertion of a muscle.

2 Define *prime mover.*

3 What is the function of a synergist? An antagonist?

Major Skeletal Muscles

This section concerns the locations, actions, origins, and insertions of some of the major skeletal muscles. The tables that summarize the information concerning groups of these muscles also include the names of nerves that supply the individual muscles within each group. Chapter 11 (pp. 000–000) presents the origins and pathways of these nerves.

Figures 9.20 and 9.21 show the locations of superficial skeletal muscles—that is, those near the surface. Notice that the names of muscles often describe them. A name may indicate a muscle's size, shape, location, action, number of attachments, or the direction of its fibers, as in the following examples:

pectoralis major A muscle of large size (*major*) located in the pectoral region (chest).
deltoid Shaped like a delta or triangle.
extensor digitorum Extends the digits (fingers or toes).
biceps brachii A muscle with two heads (*biceps*), or points of origin, located in the brachium or arm.

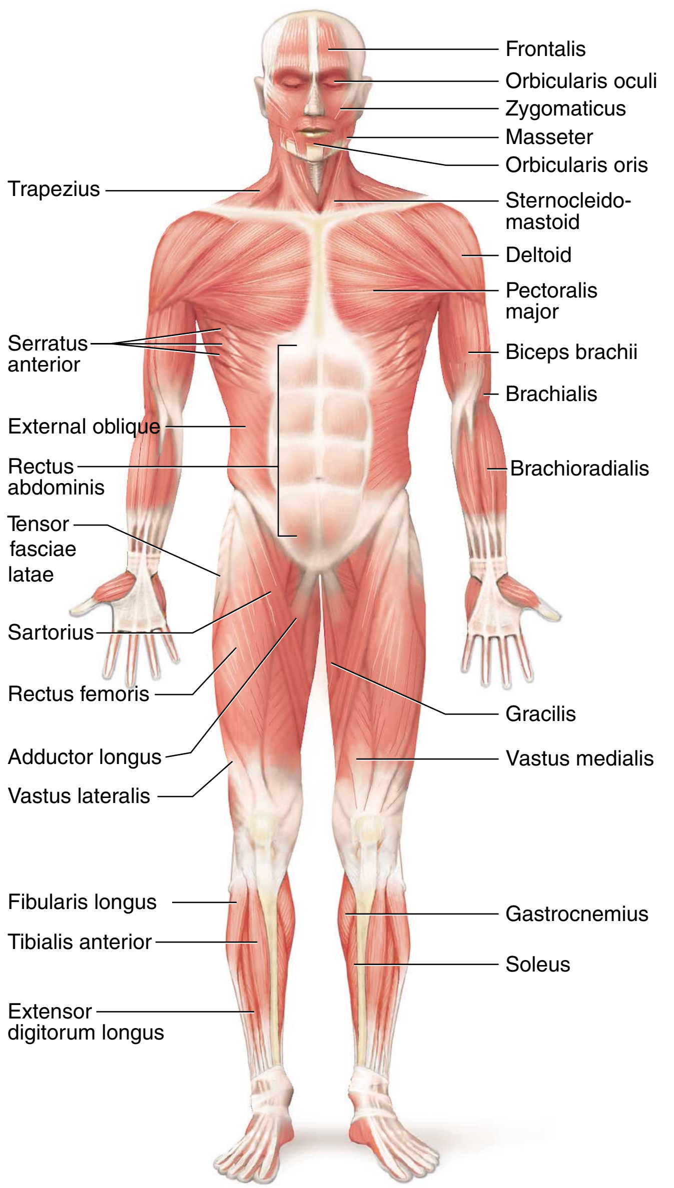


FIGURE 9.20
Anterior view of superficial skeletal muscles.

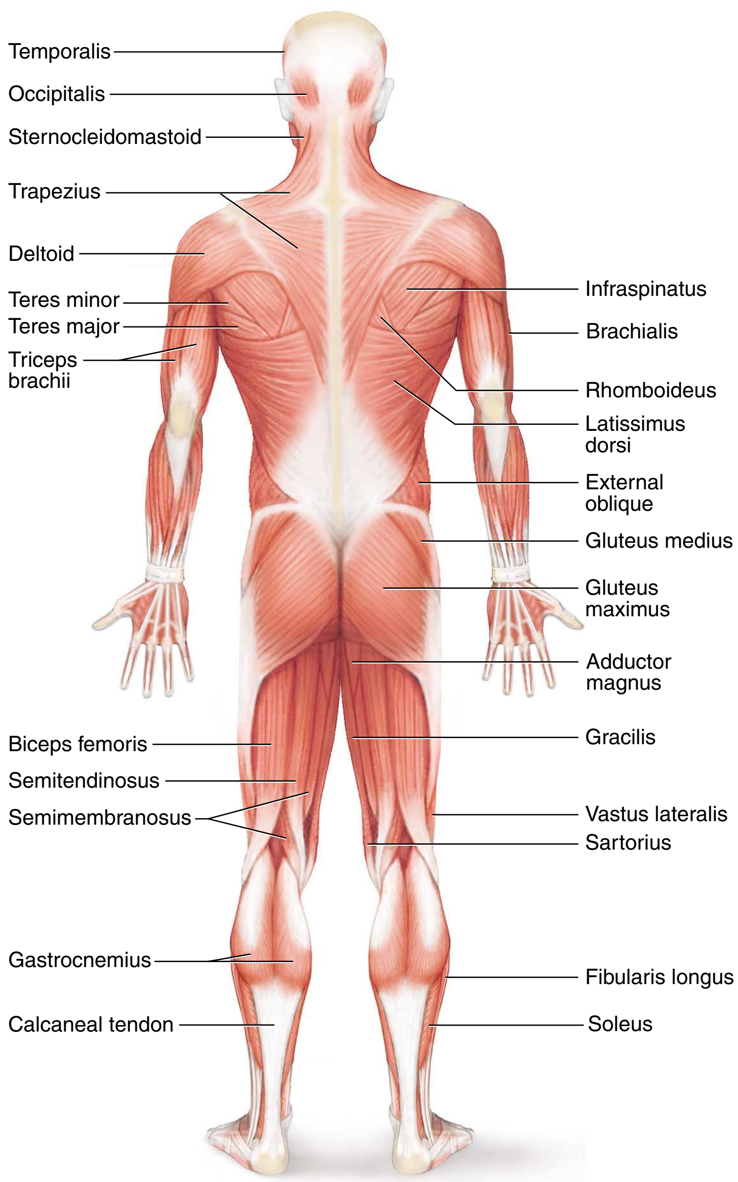


FIGURE 9.21
Posterior view of superficial skeletal muscles.

sternocleidomastoid Attached to the sternum, clavicle, and mastoid process.
external oblique Located near the outside, with fibers that run obliquely or in a slanting direction.

Muscles of Facial Expression

A number of small muscles beneath the skin of the face and scalp enable us to communicate feelings through facial expression. Many of these muscles are located around the eyes and mouth, and they make possible such expressions as surprise, sadness, anger, fear, disgust, and pain. As a group, the muscles of facial expression connect the bones of the skull to connective tissue in regions of the overlying skin. Figure 9.22 and reference plate 61 show these muscles, and table 9.3 lists them. The muscles of facial expression include the following:

Epicranius	Buccinator
Orbicularis oculi	Zygomaticus
Orbicularis oris	Platysma

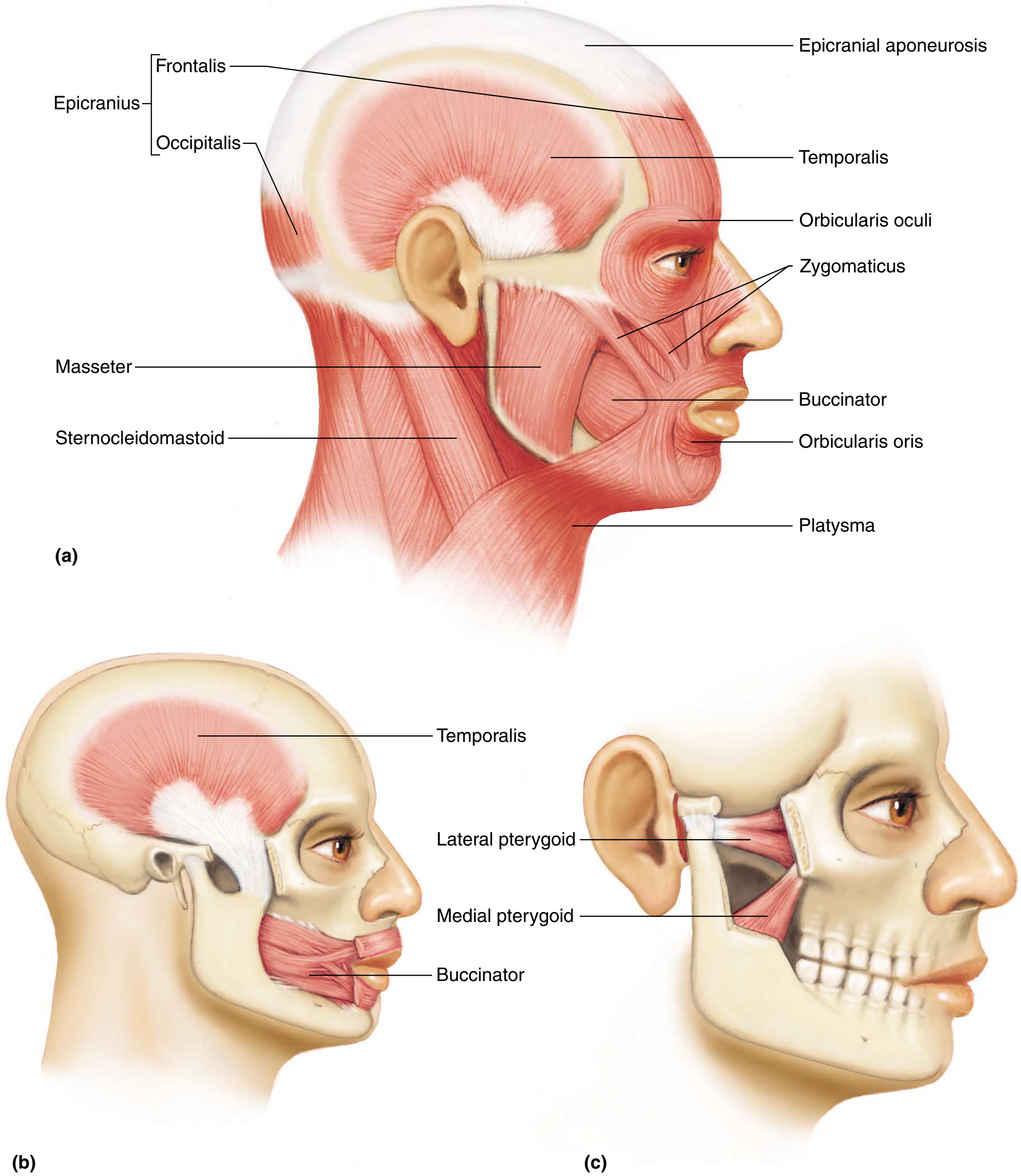


FIGURE 9.22
Muscles of head and face. (*a*) Muscles of facial expression and mastication; isolated views of (*b*) the temporalis and buccinator muscles and (*c*) the lateral and medial pterygoid muscles.

TABLE 9.3 Muscles of Facial Expression

Muscle	Origin	Insertion	Action	Nerve Supply
Epicranius	Occipital bone	Skin and muscles around eye	Raises eyebrow as when surprised	Facial n.
Orbicularis oculi	Maxillary and frontal bones	Skin around eye	Closes eye as in blinking	Facial n.
Orbicularis oris	Muscles near the mouth	Skin of central lip	Closes lips, protrudes lips as for kissing	Facial n.
Buccinator	Outer surfaces of maxilla and mandible	Orbicularis oris	Compresses cheeks inward as when blowing air	Facial n.
Zygomaticus	Zygomatic bone	Orbicularis oris	Raises corner of mouth as when smiling	Facial n.
Platysma	Fascia in upper chest	Lower border of mandible	Draws angle of mouth downward as when pouting	Facial n.

The **epicranius** (ep″ĭ-kra′ne-us) covers the upper part of the cranium and consists of two muscular parts—the *frontalis* (frun-ta′lis), which lies over the frontal bone, and the *occipitalis* (ok-sip″ĭ-ta′lis), which lies over the occipital bone. These muscles are united by a broad, tendinous membrane called the *epicranial aponeurosis,* which covers the cranium like a cap. Contraction of the epicranius raises the eyebrows and horizontally wrinkles the skin of the forehead, as when a person expresses surprise. Headaches often result from sustained contraction of this muscle.

The **orbicularis oculi** (or-bik′u-la-rus ok′u-li) is a ringlike band of muscle, called a *sphincter muscle,* that surrounds the eye. It lies in the subcutaneous tissue of the eyelid and closes or blinks the eye. At the same time, it compresses the nearby tear gland, or *lacrimal gland,* aiding the flow of tears over the surface of the eye. Contraction of the orbicularis oculi also causes the folds, or crow's feet, that radiate laterally from the corner of the eye.

The **orbicularis oris** (or-bik′u-la-rus o′ris) is a sphincter muscle that encircles the mouth. It lies between the skin and the mucous membranes of the lips, extending upward to the nose and downward to the region between the lower lip and chin. The orbicularis oris is sometimes called the kissing muscle because it closes and puckers the lips.

The **buccinator** (buk′sĭ-na″tor) is located in the wall of the cheek. Its fibers are directed forward from the bones of the jaws to the angle of the mouth, and when they contract, the cheek is compressed inward. This action helps hold food in contact with the teeth when a person is chewing. The buccinator also aids in blowing air out of the mouth, and for this reason, it is sometimes called the trumpeter muscle.

The **zygomaticus** (zi″go-mat′ik-us) extends from the zygomatic arch downward to the corner of the mouth. When it contracts, the corner of the mouth is drawn upward, as in smiling or laughing.

The **platysma** (plah-tiz′mah) is a thin, sheetlike muscle whose fibers extend from the chest upward over the neck to the face. It pulls the angle of the mouth downward, as in pouting. The platysma also helps lower the mandible. The muscles that move the eye are described in chapter 12 (pp. 000–000).

Muscles of Mastication

Four pairs of muscles attached to the mandible produce chewing movements. Three pairs of these muscles close the lower jaw, as in biting; the fourth pair can lower the jaw, cause side-to-side grinding motions of the mandible, and pull the mandible forward, causing it to protrude. The muscles of mastication are shown in figure 9.22 and reference plate 61 and are listed in table 9.4. They include the following:

Masseter	Medial pterygoid
Temporalis	Lateral pterygoid

The **masseter** (mas-se′ter) is a thick, flattened muscle that can be felt just in front of the ear when the teeth are clenched. Its fibers extend downward from the zygomatic arch to the mandible. The masseter raises the jaw, but it can also control the rate at which the jaw falls open in response to gravity (fig. 9.22*a*).

The **temporalis** (tem-po-ra′lis) is a fan-shaped muscle located on the side of the skull above and in front of the ear. Its fibers, which also raise the jaw, pass downward beneath the zygomatic arch to the mandible (fig. 9.22*a* and *b*). Tensing this muscle is associated with temporomandibular joint syndrome, discussed in Clinical Application 9.3.

The **medial pterygoid** (ter′ĭ-goid) extends back and downward from the sphenoid, palatine, and maxillary bones to the ramus of the mandible. It closes the jaw (fig. 9.22*c*) and moves it from side to side.

The fibers of the **lateral pterygoid** extend forward from the region just below the mandibular condyle to the sphenoid bone. This muscle can open the mouth, pull the

9.3 CLINICAL APPLICATION

TMJ Syndrome

Facial pain, headache, ringing in the ears, a clicking jaw, insomnia, teeth sensitive to heat or cold, backache, dizziness, and pain in front of the ears are aches and pains that may all result from temporomandibular joint (TMJ) syndrome. This condition is caused by a misaligned jaw or simply by a habit of grinding or clenching the teeth. These conditions may stress the temporomandibular joint, the articulation between the mandibular condyle of the mandible and the mandibular fossa of the temporal bone. Loss of coordination of these structures affects the nerves that pass through the neck and jaw region, causing the symptoms. In TMJ syndrome, tensing a muscle in the forehead can cause a headache, or a spasm in the muscle that normally opens the auditory tubes during swallowing can impair ability to clear the ears.

Doctors diagnose TMJ syndrome using an electromyograph, in which electrodes record muscle activity in four pairs of head and neck muscle groups. A form of treatment is transcutaneous electrical nerve stimulation (TENS), which stimulates the facial muscles for up to an hour. Another treatment is an orthotic device fitted by a dentist. Worn for three to six months, the device fine-tunes the action of jaw muscles to form a more comfortable bite. Finally, once the correct bite is determined, a dentist can use bonding materials to alter shapes of certain teeth to provide a more permanent treatment for TMJ syndrome. ■

TABLE 9.4 Muscles of Mastication

Muscle	Origin	Insertion	Action	Nerve Supply
Masseter	Lower border of zygomatic arch	Lateral surface of mandible	Elevates mandible	Trigeminal n.
Temporalis	Temporal bone	Coronoid process and anterior ramus of mandible	Elevates mandible	Trigeminal n.
Medial pterygoid	Sphenoid, palatine, and maxillary bones	Medial surface of mandible	Elevates mandible and moves it from side to side	Trigeminal n.
Lateral pterygoid	Sphenoid bone	Anterior surface of mandibular condyle	Depresses and protracts mandible and moves it from side to side	Trigeminal n.

mandible forward to make it protrude, and move the mandible from side to side (fig. 9.22*c*).

When, in 1995, two dentists examined an eyeless cadaver's skull from an unusual perspective, they discovered an apparently newly seen muscle in the head. Named the sphenomandibularis, the muscle extends about an inch and a half from behind the eyes to the inside of the jawbone and may assist chewing movements. In traditional dissection from the side, the new muscle's origin and insertion are not visible, so it may have appeared to be part of the larger and overlying temporalis muscle. Although the sphenomandibularis inserts on the inner side of the jawbone, as does the temporalis, it originates differently, on the sphenoid bone. The dentists then identified the sphenomandibularis in twenty-five other cadavers, and other researchers found it in live patients undergoing MRI scans.

Muscles That Move the Head and Vertebral Column

Paired muscles in the neck and back flex, extend, and rotate the head and hold the torso erect (figs. 9.23 and 9.25 and table 9.5). They include the following:

Sternocleidomastoid	Semispinalis capitis
Splenius capitis	Erector spinae

The **sternocleidomastoid** (ster″no-kli″do-mas′toid) is a long muscle in the side of the neck that extends upward from the thorax to the base of the skull behind the ear. When the sternocleidomastoid on one side contracts, the face turns to the opposite side. When both muscles contract, the head bends toward the chest. If other muscles fix the head in position, the sternocleidomastoids can raise the sternum, aiding forceful inhalation (fig. 9.25 and table 9.5).

The **splenius capitis** (sple′ne-us kap′ĭ-tis) is a broad, straplike muscle in the back of the neck. It connects the base of the skull to the vertebrae in the neck and upper

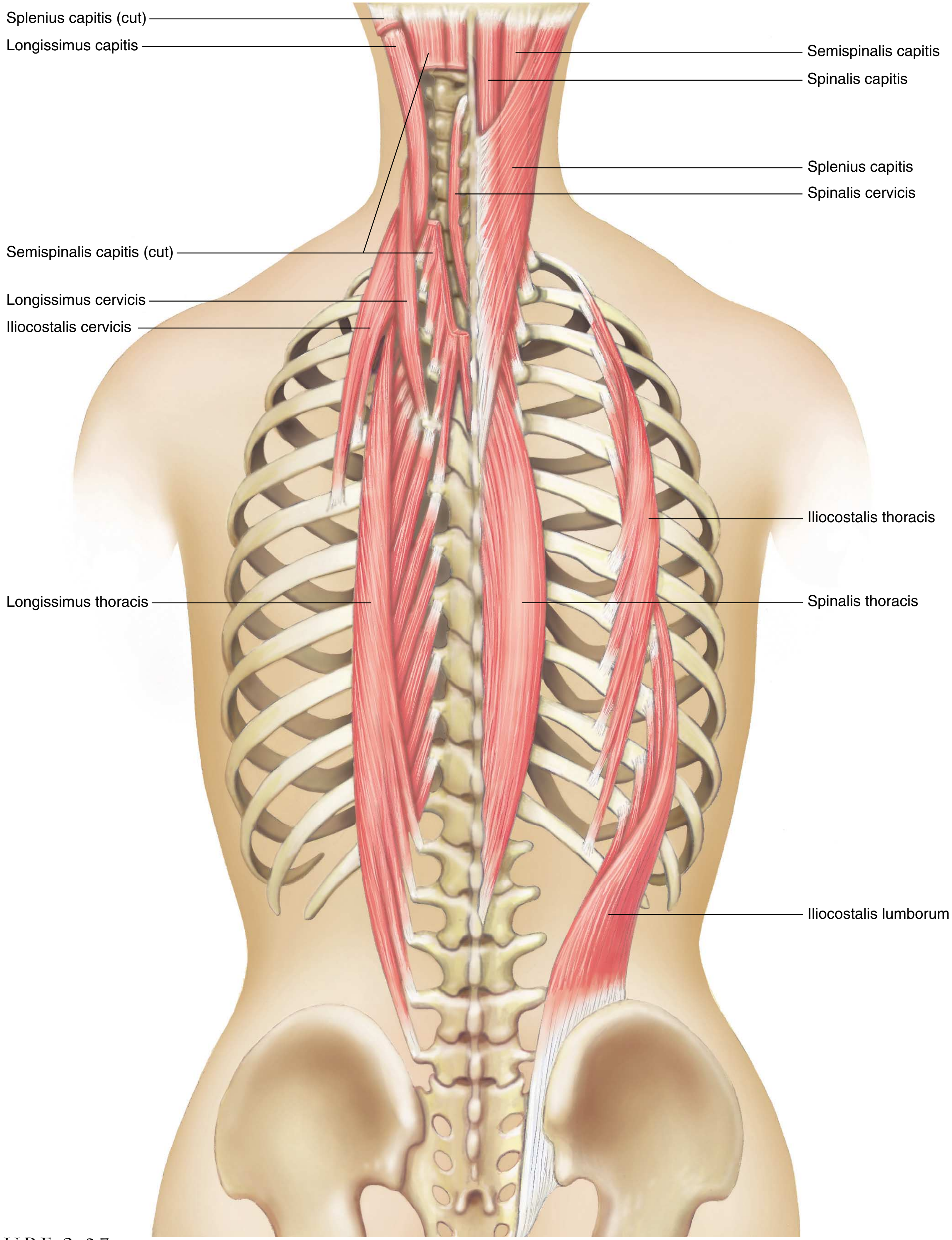


FIGURE 9.23
Deep muscles of the back and the neck help move the head (posterior view) and hold the torso erect. The splenius capitis and semispinalis capitis are removed on the left to show underlying muscles.

TABLE 9.5 Muscles That Move the Head and Vertebral Column

Muscle	Origin	Insertion	Action	Nerve Supply
Sternocleidomastoid	Anterior surface of sternum and upper surface of clavicle	Mastoid process of temporal bone	Pulls head to one side, flexes neck or elevates sternum	Accessory, C2 and C3 cervical nerves
Splenius capitis	Spinous processes of lower cervical and upper thoracic vertebrae	Occipital bone	Rotates head, bends head to one side, or extends neck	Cervical nerves
Semispinalis capitis	Processes of lower cervical and upper thoracic vertebrae	Occipital bone	Extends head, bends head to one side, or rotates head	Cervical and thoracic spinal nerves
Erector spinae				
Iliocostalis (lateral) group				
Iliocostalis lumborum	Iliac crest	Lower six ribs	Extends lumbar region of vertebral column	Lumbar spinal nerves
Iliocostalis thoracis	Lower six ribs	Upper six ribs	Holds spine erect	Thoracic spinal nerves
Iliocostalis cervicis	Upper six ribs	Fourth through sixth cervical vertebrae	Extends cervical region of vertebral column	Cervical spinal nerves
Longissimus (intermediate) group				
Longissimus thoracis	Lumbar vertebrae	Thoracic and upper lumbar vertebrae and ribs 9 and 10	Extends thoracic region of vertebral column	Spinal nerves
Longissimus cervicis	Fourth and fifth thoracic vertebrae	Second through sixth cervical vertebrae	Extends cervical region of vertebral column	Spinal nerves
Longissimus capitis	Upper thoracic and lower cervical vertebrae	Mastoid process of temporal bone	Extends and rotates head	Cervical spinal nerves
Spinalis (medial) group				
Spinalis thoracis	Upper lumbar and lower thoracic vertebrae	Upper thoracic vertebrae	Extends vertebral column	Spinal nerves
Spinalis cervicis	Ligamentum nuchae and seventh cervical vertebra	Axis	Extends vertebral column	Spinal nerves
Spinalis capitis	Upper thoracic and lower cervical vertebrae	Occipital bone	Extends vertebral column	Spinal nerves

thorax. A splenius capitis acting singly rotates the head and bends it toward one side. Acting together, these muscles bring the head into an upright position (fig. 9.23 and table 9.5).

The **semispinalis capitis** (sem″e-spi-na′lis kap′ĭ-tis) is a broad, sheetlike muscle extending upward from the vertebrae in the neck and thorax to the occipital bone. It extends the head, bends it to one side, or rotates it (fig. 9.23 and table 9.5).

Erector spinae muscles run longitudinally along the back, with origins and insertions at many places on the axial skeleton. These muscles extend and rotate the head and maintain the erect position of the vertebral column. Erector spinae can be subdivided into lateral, intermediate, and medial groups (table 9.5).

Muscles That Move the Pectoral Girdle

The muscles that move the pectoral girdle are closely associated with those that move the arm. A number of these chest and shoulder muscles connect the scapula to nearby bones and move the scapula upward, downward, forward, and backward (figs. 9.24, 9.25, 9.26; reference plates 63, 64; table 9.6). Muscles that move the pectoral girdle include the following:

Trapezius	Serratus anterior
Rhomboideus major	Pectoralis minor
Levator scapulae	

The **trapezius** (trah-pe′ze-us) is a large, triangular muscle in the upper back that extends horizontally from the base of the skull and the cervical and thoracic vertebrae to the shoulder. Its fibers are arranged into three groups—upper, middle, and lower. Together these fibers rotate the scapula. The upper fibers acting alone raise the scapula and shoulder, as when the shoulders are shrugged to express a feeling of indifference. The middle fibers pull the scapula toward the vertebral column, and the lower fibers draw the scapula and shoulder downward. When other muscles fix the shoulder in position, the trapezius can pull the head backward or to one side (fig. 9.24).

The **rhomboideus** (rom-boid′-ē-us) **major** connects the upper thoracic vertebrae to the scapula. It raises the scapula and adducts it (fig. 9.24).

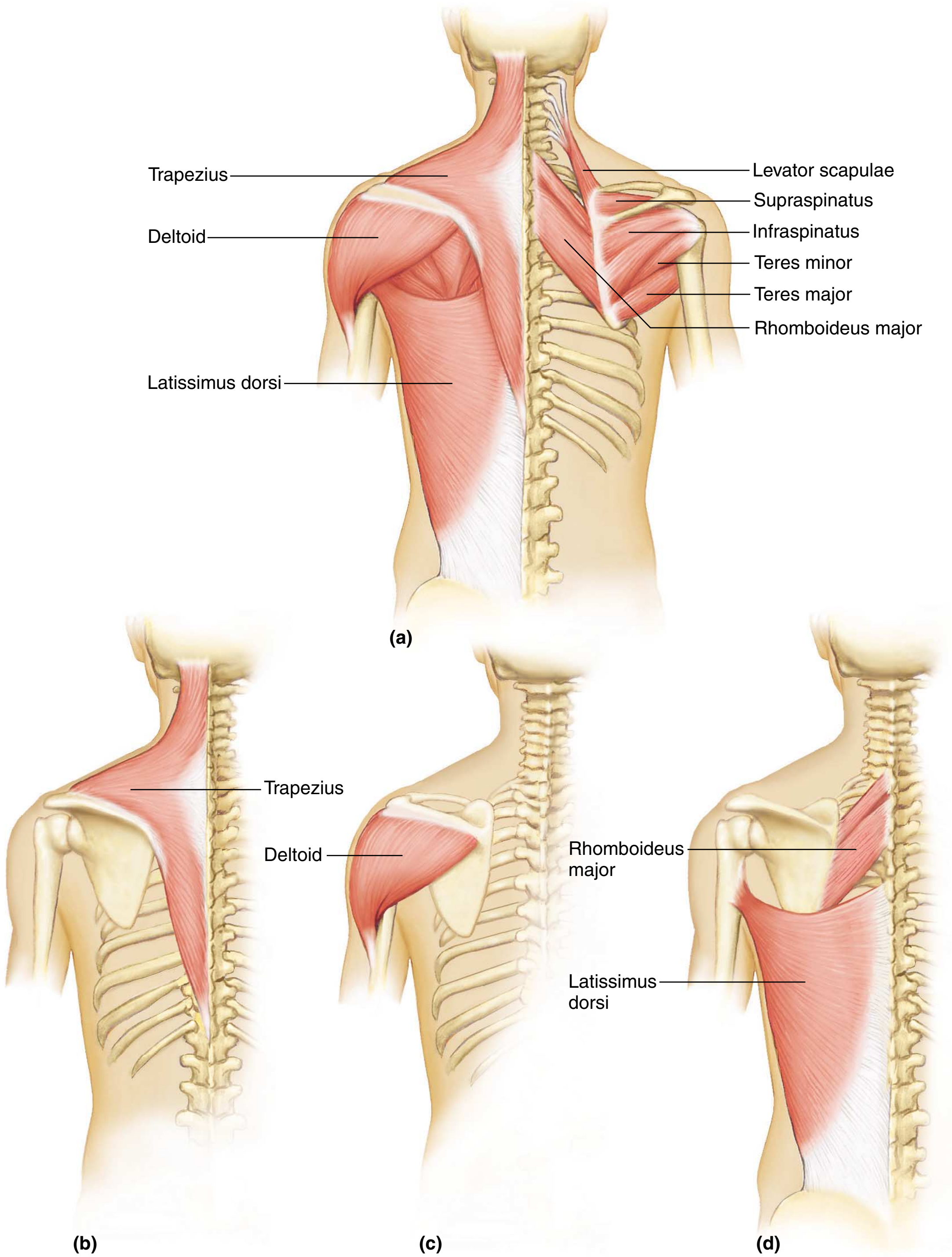


FIGURE 9.24

Muscles of the shoulder and back. (*a*) Muscles of the posterior shoulder. The right trapezius is removed to show underlying muscles. Isolated views of (*b*) trapezius, (*c*) deltoid, and (*d*) rhomboideus and latissimus dorsi muscles.

The **levator scapulae** (le-va′tor scap′u-lē) is a straplike muscle that runs almost vertically through the neck, connecting the cervical vertebrae to the scapula. It elevates the scapula (figs. 9.24 and 9.26).

The **serratus anterior** (ser-ra′tus an-te′re-or) is a broad, curved muscle located on the side of the chest. It arises as fleshy, narrow strips on the upper ribs and extends along the medial wall of the axilla to the ventral surface of the scapula. It pulls the scapula downward and anteriorly and is used to thrust the shoulder forward, as when pushing something (fig. 9.25).

The **pectoralis** (pek″to-ra′lis) **minor** is a thin, flat muscle that lies beneath the larger pectoralis major. It extends laterally and upward from the ribs to the scapula and pulls

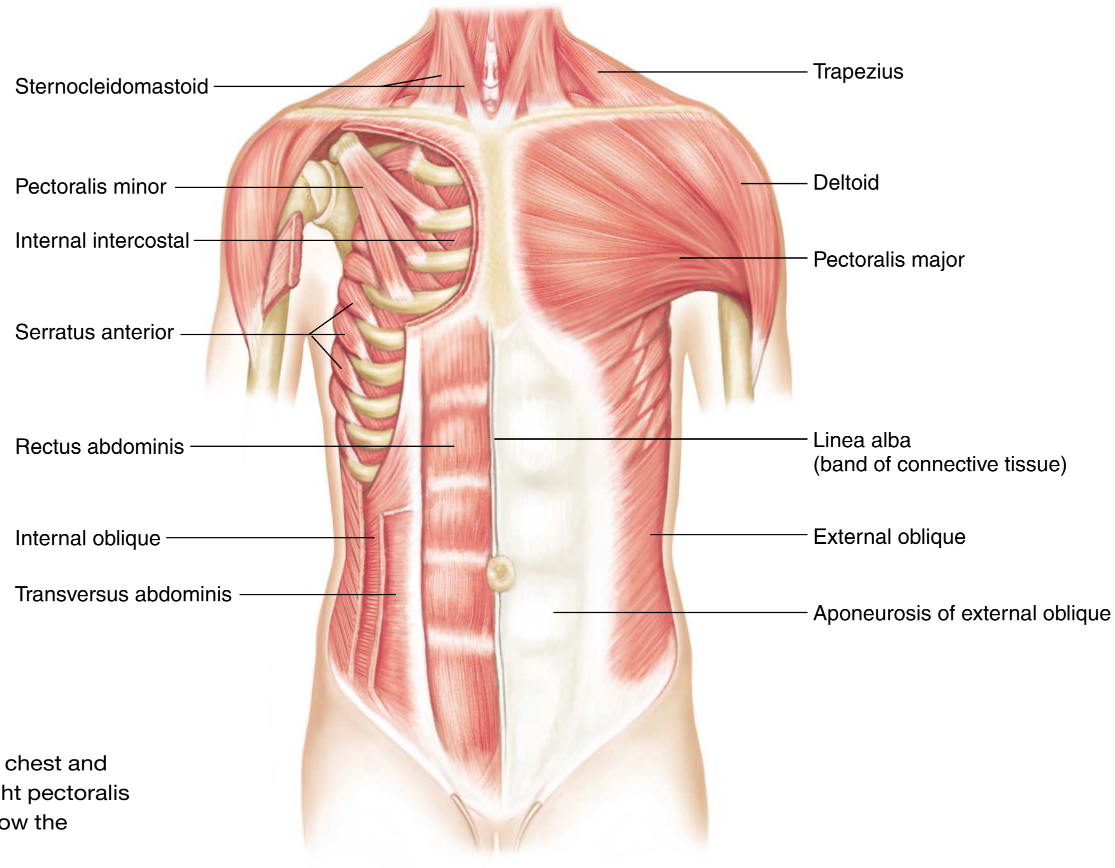


FIGURE 9.25
Muscles of the anterior chest and abdominal wall. The right pectoralis major is removed to show the pectoralis minor.

TABLE 9.6 Muscles That Move the Pectoral Girdle

Muscle	Origin	Insertion	Action	Nerve Supply
Trapezius	Occipital bone and spines of cervical and thoracic vertebrae	Clavicle, spine, and acromion process of scapula	Rotates scapula; various fibers raise scapula, pull scapula medially, or pull scapula and shoulder downward	Accessory n.
Rhomboideus major	Spines of upper thoracic vertebrae	Medial border of scapula	Raises and adducts scapula	Dorsal scapular n.
Levator scapulae	Transverse processes of cervical vertebrae	Medial margin of scapula	Elevates scapula	Dorsal scapular and cervical nerves
Serratus anterior	Outer surfaces of upper ribs	Ventral surface of scapula	Pulls scapula anteriorly and downward	Long thoracic n.
Pectoralis minor	Sternal ends of upper ribs	Coracoid process of scapula	Pulls scapula forward and downward or raises ribs	Pectoral n.

A small, triangular region, called the *triangle of auscultation,* is located in the back where the trapezius overlaps the superior border of the latissimus dorsi and the underlying rhomboideus major. This area, which is near the medial border of the scapula, enlarges when a person bends forward with the arms folded across the chest. By placing the bell of a stethoscope within the triangle of auscultation, a physician can usually clearly hear the sounds of the respiratory organs.

the scapula forward and downward. When other muscles fix the scapula in position, the pectoralis minor can raise the ribs and thus aid forceful inhalation (fig. 9.25).

Muscles That Move the Arm

The arm is one of the more freely movable parts of the body because muscles connect the humerus to regions of the pectoral girdle, ribs, and vertebral column. These muscles can be grouped according to their primary actions—flexion, extension, abduction, and rotation (figs.

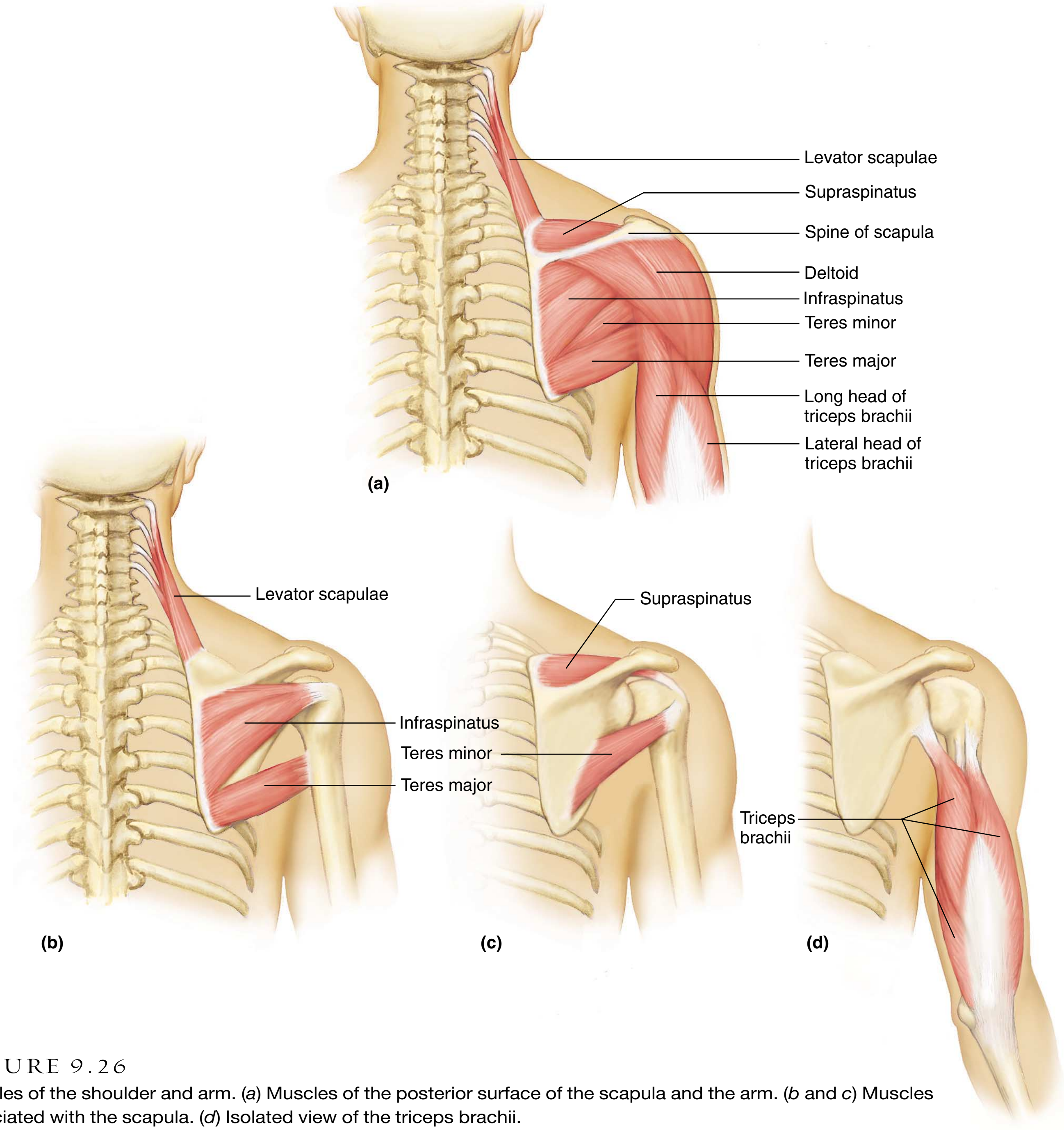


FIGURE 9.26
Muscles of the shoulder and arm. (*a*) Muscles of the posterior surface of the scapula and the arm. (*b* and *c*) Muscles associated with the scapula. (*d*) Isolated view of the triceps brachii.

9.26, 9.27, 9.28; reference plates 62, 63, 64; table 9.7). Muscles that move the arm include the following:

Flexors	**Abductors**
Coracobrachialis	Supraspinatus
Pectoralis major	Deltoid
Extensors	**Rotators**
Teres major	Subscapularis
Latissimus dorsi	Infraspinatus
	Teres minor

Flexors

The **coracobrachialis** (kor″ah-ko-bra′ke-al-is) extends from the scapula to the middle of the humerus along its medial surface. It flexes and adducts the arm (figs. 9.27 and 9.28).

The **pectoralis major** is a thick, fan-shaped muscle located in the upper chest. Its fibers extend from the center of the thorax through the armpit to the humerus. This muscle primarily pulls the arm forward and across the chest. It can also rotate the humerus medially and adduct the arm from a raised position (fig. 9.25).

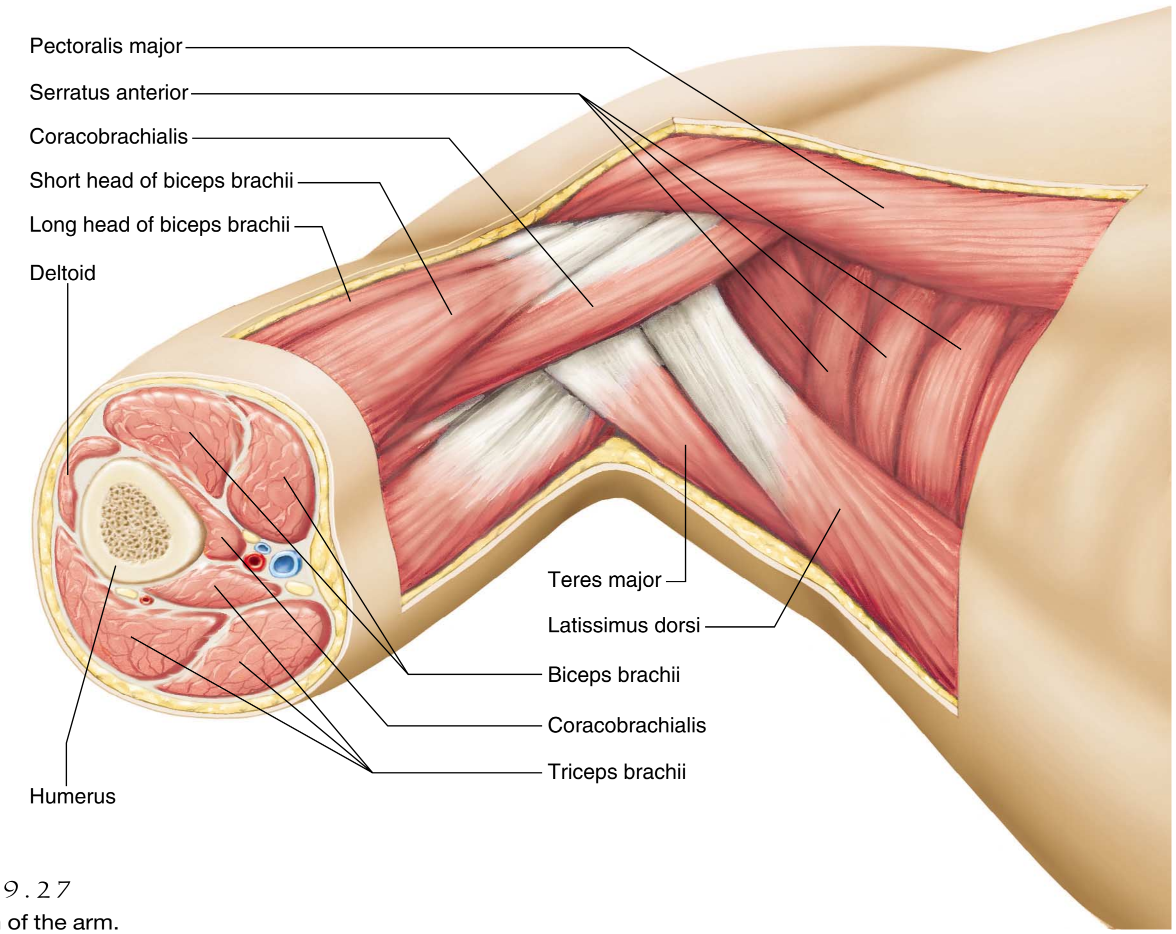


FIGURE 9.27
Cross section of the arm.

TABLE 9.7 Muscles That Move the Arm

Muscle	Origin	Insertion	Action	Nerve Supply
Coracobrachialis	Coracoid process of scapula	Shaft of humerus	Flexes and adducts the arm	Musculocutaneus n.
Pectoralis major	Clavicle, sternum, and costal cartilages of upper ribs	Intertubercular groove of humerus	Flexes, adducts, and rotates arm medially	Pectoral n.
Teres major	Lateral border of scapula	Intertubercular groove of humerus	Extends, adducts, and rotates arm medially	Lower subscapular n.
Latissimus dorsi	Spines of sacral, lumbar, and lower thoracic vertebrae, iliac crest, and lower ribs	Intertubercular groove of humerus	Extends, adducts, and rotates the arm medially, or pulls the shoulder downward and back	Thoracodorsal n.
Supraspinatus	Posterior surface of scapula above spine	Greater tubercle of humerus	Abducts the arm	Suprascapular n.
Deltoid	Acromion process, spine of the scapula, and the clavicle	Deltoid tuberosity of humerus	Abducts, extends, and flexes arm	Axillary n.
Subscapularis	Anterior surface of scapula	Lesser tubercle of humerus	Rotates arm medially	Subscapular n.
Infraspinatus	Posterior surface of scapula below spine	Greater tubercle of humerus	Rotates arm laterally	Suprascapular n.
Teres minor	Lateral border of scapula	Greater tubercle of humerus	Rotates arm laterally	Axillary n.

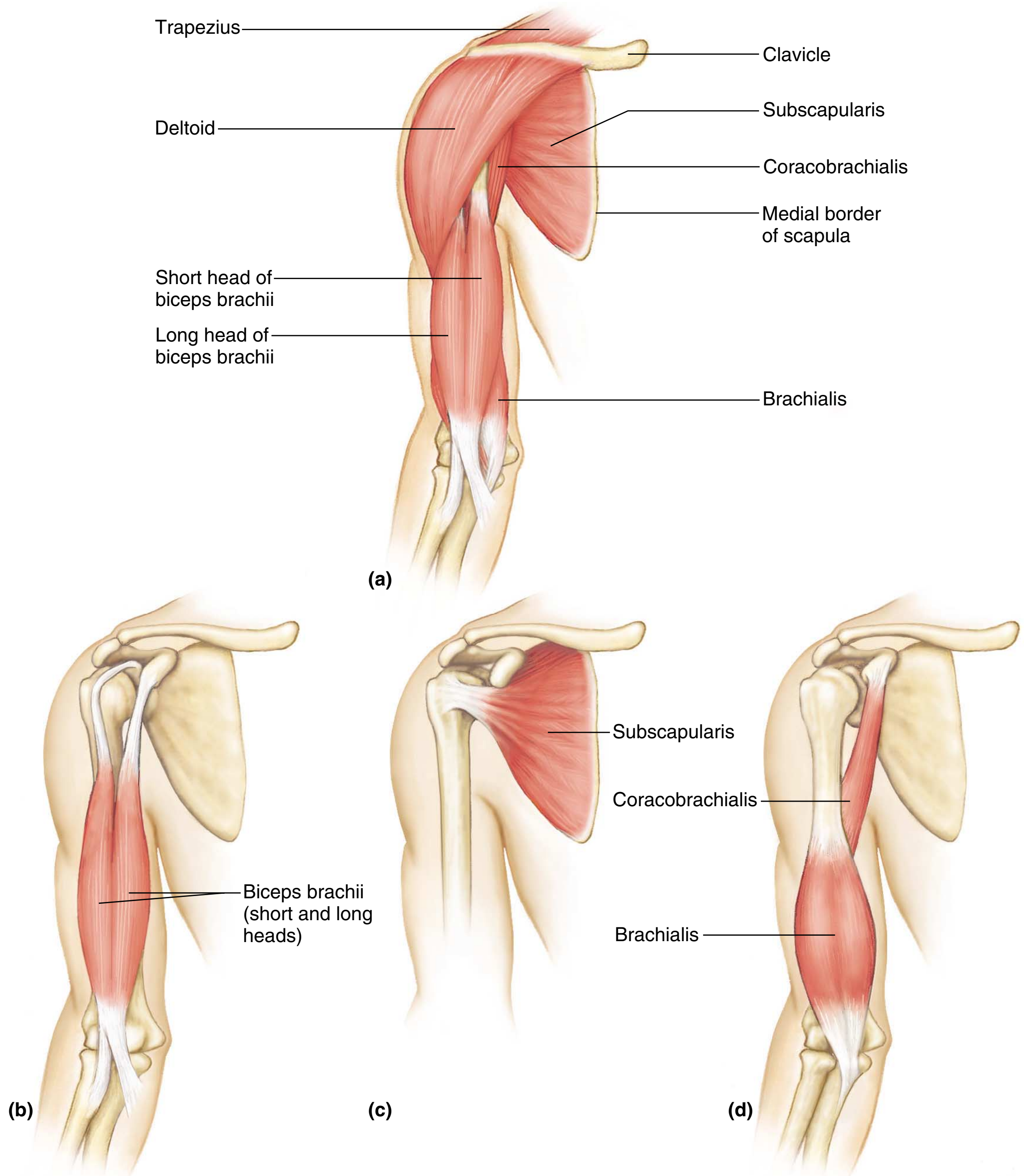


FIGURE 9.28
Muscles of the shoulder and arm. (*a*) Muscles of the anterior shoulder and the arm, with the rib cage removed. (*b, c,* and *d*) Isolated views of muscles associated with the arm.

Extensors

The **teres** (te′rēz) **major** connects the scapula to the humerus. It extends the humerus and can also adduct and rotate the arm medially (figs. 9.24 and 9.26).

The **latissimus dorsi** (lah-tis′ĭ-mus dor′si) is a wide, triangular muscle that curves upward from the lower back, around the side, and to the armpit. It can extend and adduct the arm and rotate the humerus medially. It also pulls the shoulder downward and back. This muscle is used to pull the arm back in swimming, climbing, and rowing (figs. 9.24 and 9.27).

Abductors

The **supraspinatus** (su″prah-spi′na-tus) is located in the depression above the spine of the scapula on its posterior surface. It connects the scapula to the greater tubercle of the humerus and abducts the arm (figs. 9.24 and 9.26).

The **deltoid** (del′toid) is a thick, triangular muscle that covers the shoulder joint. It connects the clavicle and scapula to the lateral side of the humerus and abducts the arm. The deltoid's posterior fibers can extend the humerus, and its anterior fibers can flex the humerus (fig. 9.24).

A humerus fractured at its surgical neck may damage the axillary nerve that supplies the deltoid muscle (see fig. 7.45). If this occurs, the muscle is likely to shrink and weaken. In order to test the deltoid for such weakness, a physician may ask a patient to abduct the arm against some resistance and maintain that posture for a time.

Rotators

The **subscapularis** (sub-scap′u-lar-is) is a large, triangular muscle that covers the anterior surface of the scapula. It connects the scapula to the humerus and rotates the arm medially (fig. 9.28).

The **infraspinatus** (in″frah-spi′na-tus) occupies the depression below the spine of the scapula on its posterior surface. The fibers of this muscle attach the scapula to the humerus and rotate the arm laterally (fig. 9.26).

The **teres minor** is a small muscle connecting the scapula to the humerus. It rotates the arm laterally (figs. 9.24 and 9.26).

Muscles That Move the Forearm

Most forearm movements are produced by muscles that connect the radius or ulna to the humerus or pectoral girdle. A group of muscles located along the anterior surface of the humerus flexes the forearm at the elbow, whereas a single posterior muscle extends this joint. Other muscles cause movements at the radioulnar joint and rotate the forearm.

The muscles that move the forearm are shown in figures 9.28, 9.29, 9.30, 9.31, in reference plates 63, 65, and are listed in table 9.8, grouped according to their primary actions. They include the following:

Flexors	**Extensor**	**Rotators**
Biceps brachii	Triceps brachii	Supinator
Brachialis		Pronator teres
Brachioradialis		Pronator quadratus

Flexors

The **biceps brachii** (bi′seps bra′ke-i) is a fleshy muscle that forms a long, rounded mass on the anterior side of the arm. It connects the scapula to the radius and flexes the forearm at the elbow and rotates the hand laterally (supination), as when a person turns a doorknob or screwdriver (fig. 9.28).

The **brachialis** (bra′ke-al-is) is a large muscle beneath the biceps brachii. It connects the shaft of the humerus to the ulna and is the strongest flexor of the elbow (fig. 9.28).

The **brachioradialis** (bra″ke-o-ra″de-a′lis) connects the humerus to the radius. It aids in flexing the elbow (fig. 9.29).

Extensor

The **triceps brachii** (tri′seps bra′ke-i) has three heads and is the only muscle on the back of the arm. It connects the humerus and scapula to the ulna and is the primary extensor of the elbow (figs. 9.26 and 9.27).

Rotators

The **supinator** (su′pĭ-na-tor) is a short muscle whose fibers run from the ulna and the lateral end of the humerus to the radius. It assists the biceps brachii in rotating the forearm laterally (supination) (fig. 9.29).

The **pronator teres** (pro-na′tor te′rēz) is a short muscle connecting the ends of the humerus and ulna to the radius.

TABLE 9.8 Muscles That Move the Forearm

Muscle	Origin	Insertion	Action	Nerve Supply
Biceps brachii	Coracoid process and tubercle above glenoid cavity of scapula	Radial tuberosity of radius	Flexes forearm at elbow and rotates hand laterally	Musculocutaneous n.
Brachialis	Anterior shaft of humerus	Coronoid process of ulna	Flexes forearm at elbow	Musculocutaneous, median, and radial nerves
Brachioradialis	Distal lateral end of humerus	Lateral surface of radius above styloid process	Flexes forearm at elbow	Radial n.
Triceps brachii	Tubercle below glenoid cavity and lateral and medial surfaces of humerus	Olecranon process of ulna	Extends forearm at elbow	Radial n.
Supinator	Lateral epicondyle of humerus and crest of ulna	Lateral surface of radius	Rotates forearm laterally	Radial n.
Pronator teres	Medial epicondyle of humerus and coronoid process of ulna	Lateral surface of radius	Rotates forearm medially	Median n.
Pronator quadratus	Anterior distal end of ulna	Anterior distal end of radius	Rotates forearm medially	Median n.

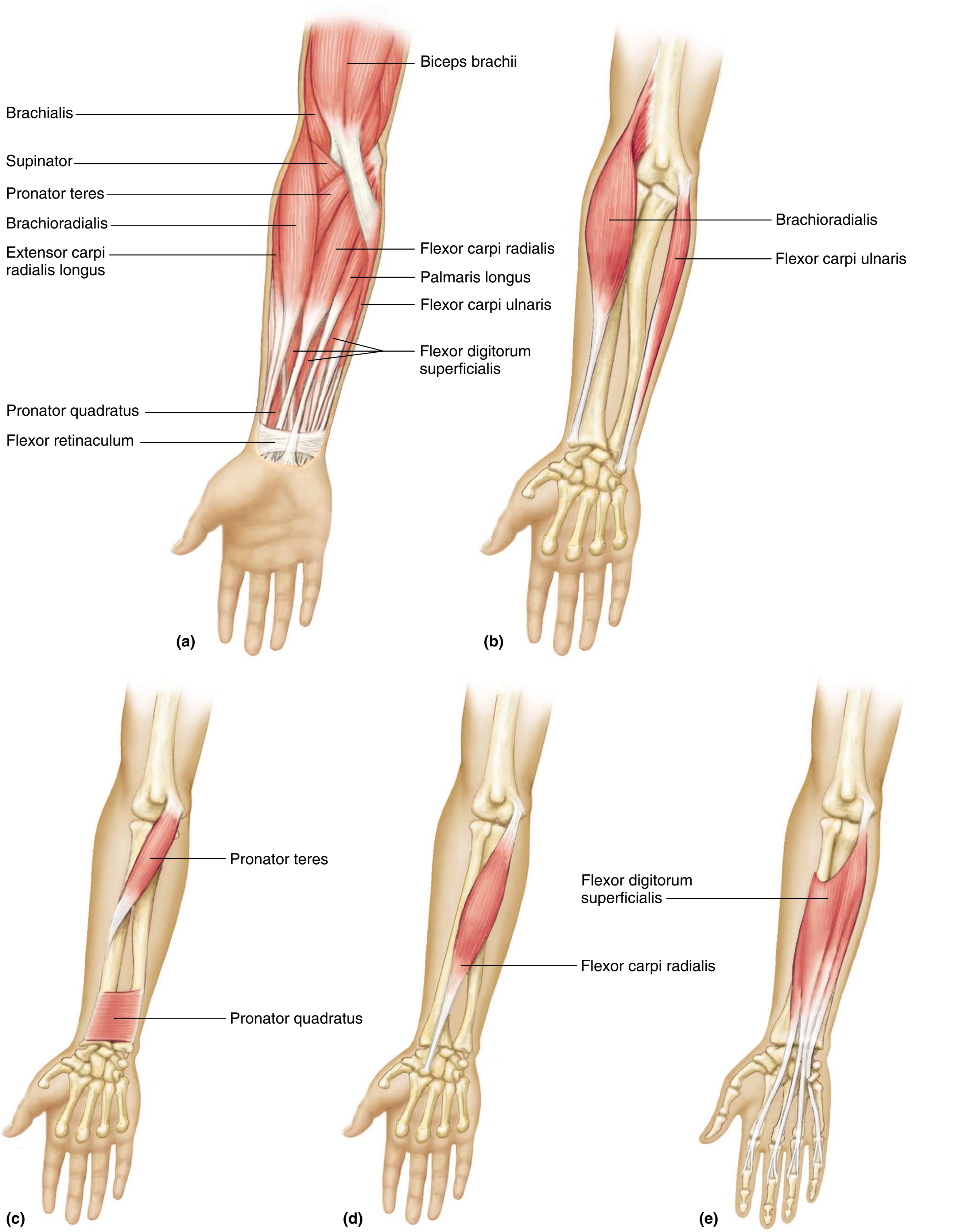


FIGURE 9.29

Muscles of the arm and forearm. (*a*) Muscles of the anterior forearm. (*b*–*e*) Isolated views of muscles associated with the anterior forearm.

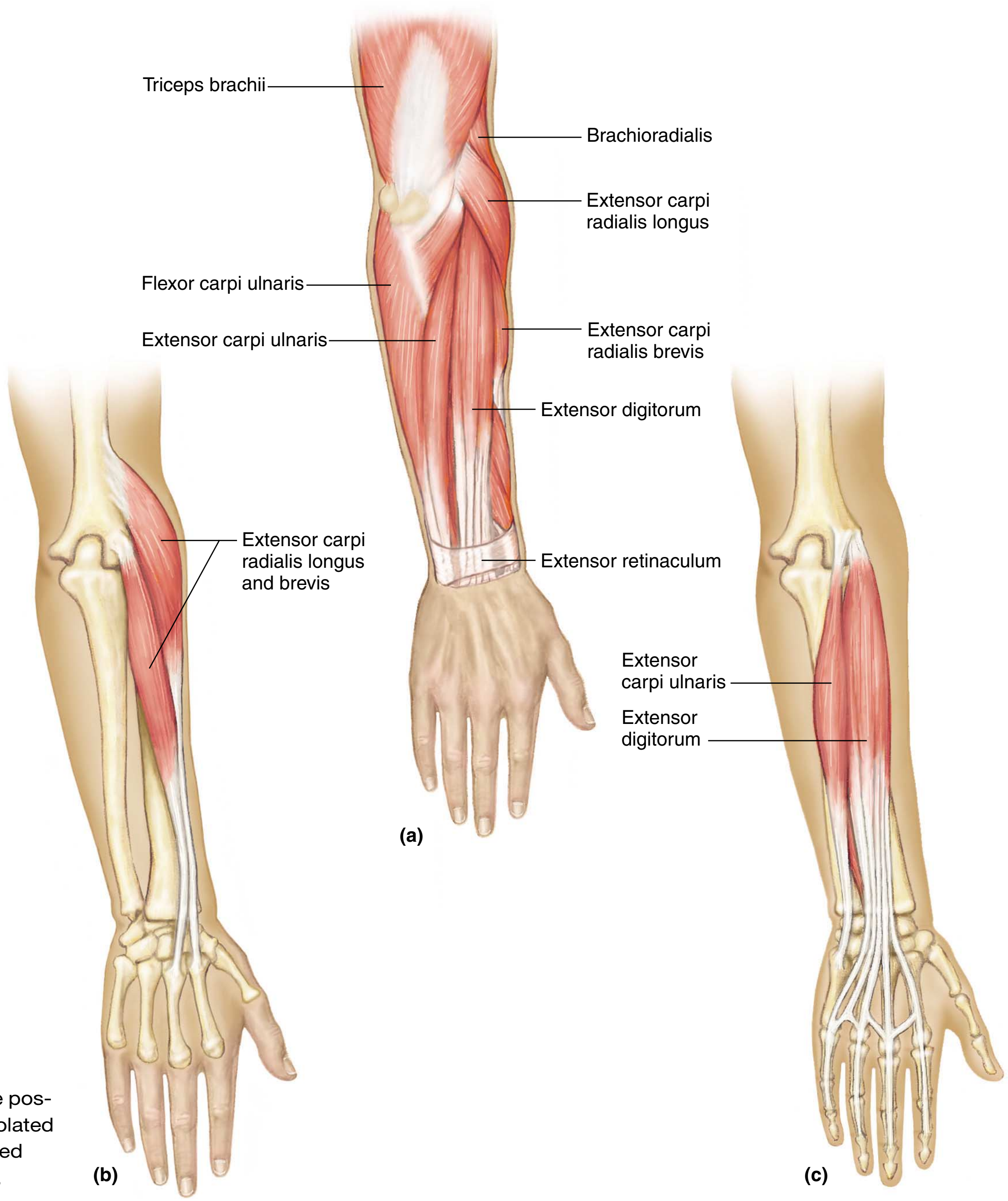


FIGURE 9.30
Muscles of the arm and forearm. (*a*) Muscles of the posterior forearm. (*b* and *c*) Isolated views of muscles associated with the posterior forearm.

It rotates the arm medially, as when the hand is turned so the palm is facing downward (pronation) (fig. 9.29).

The **pronator quadratus** (pro-na′tor kwod-ra′tus) runs from the distal end of the ulna to the distal end of the radius. It assists the pronator teres in rotating the arm medially (fig. 9.29).

Muscles That Move the Hand

Movements of the hand include movements of the wrist and fingers. Many muscles move the wrist, hand, and fingers. They originate from the distal end of the humerus and from the radius and ulna. The two major groups of these muscles are flexors on the anterior side of the forearm and extensors on the posterior side. Figures 9.29, 9.30, 9.31, reference plate 65, and table 9.9 concern these muscles. The muscles that move the hand include the following:

Flexors	**Extensors**
Flexor carpi radialis longus	Extensor carpi radialis
Flexor carpi ulnaris	Extensor carpi radialis brevis
Palmaris longus	Extensor carpi ulnaris
Flexor digitorum profundus	Extensor digitorum
Flexor digitorum superficialis	

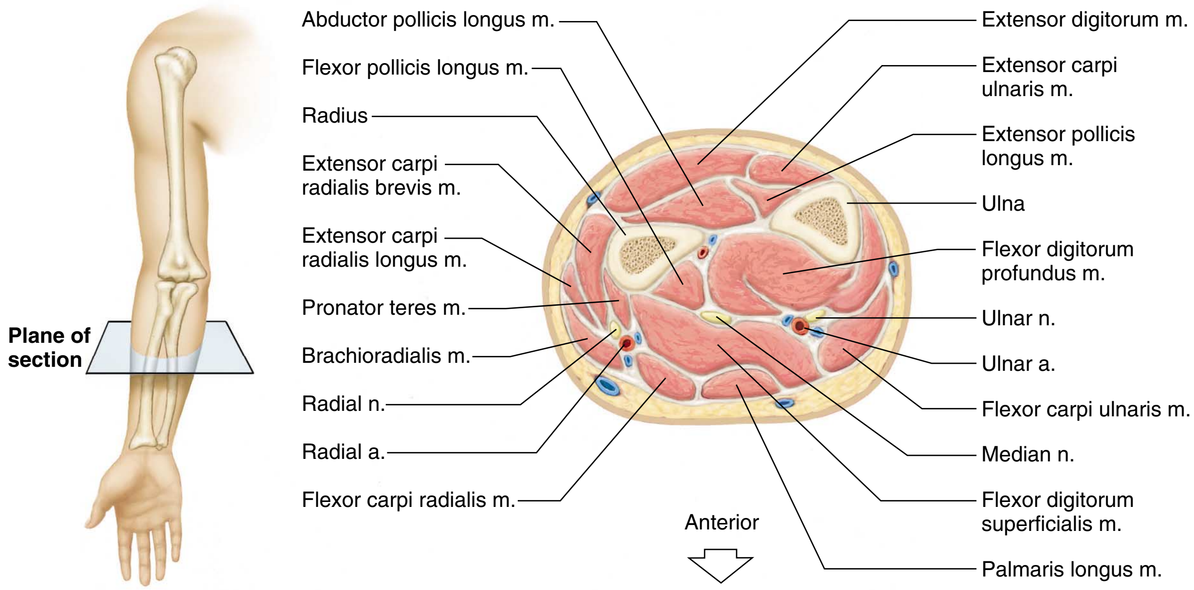


FIGURE 9.31
A cross section of the forearm (superior view).

TABLE 9.9 Muscles That Move the Hand

Muscle	Origin	Insertion	Action	Nerve Supply
Flexor carpi radialis	Medial epicondyle of humerus	Base of second and third metacarpals	Flexes and abducts hand at the wrist	Median n.
Flexor carpi ulnaris	Medial epicondyle of humerus and olecranon process	Carpal and metacarpal bones	Flexes and adducts hand at the wrist	Ulnar n.
Palmaris longus	Medial epicondyle of humerus	Fascia of palm	Flexes hand at the wrist	Median n.
Flexor digitorum profundus	Anterior surface of ulna	Bases of distal phalanges in fingers 2–5	Flexes distal joints of fingers	Median and ulnar nerves
Flexor digitorum superficialis	Medial epicondyle of humerus, coronoid process of ulna, and radius	Tendons of fingers	Flexes fingers and hand	Median n.
Extensor carpi radialis longus	Distal end of humerus	Base of second metacarpal	Extends and abducts hand at the wrist	Radial n.
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of second and third metacarpals	Extends and abducts hand at the wrist	Radial n.
Extensor carpi ulnaris	Lateral epicondyle of humerus	Base of fifth metacarpal	Extends and adducts hand at the wrist	Radial n.
Extensor digitorum	Lateral epicondyle of humerus	Posterior surface of phalanges in fingers 2–5	Extends fingers	Radial n.

Flexors

The **flexor carpi radialis** (flek′sor kar-pi′ra″de-a′lis) is a fleshy muscle that runs medially on the anterior side of the forearm. It extends from the distal end of the humerus into the hand, where it is attached to metacarpal bones. The flexor carpi radialis flexes and abducts the hand at the wrist (fig. 9.29).

The **flexor carpi ulnaris** (flek′sor kar-pi′ ul-na′ris) is located along the medial border of the forearm. It connects the distal end of the humerus and the proximal end of the ulna to carpal and metacarpal bones. It flexes and adducts the hand at the wrist (fig. 9.29).

The **palmaris longus** (pal-ma′ris long′gus) is a slender muscle located on the medial side of the forearm between the flexor carpi radialis and the flexor carpi ulnaris. It connects the distal end of the humerus to fascia of the palm and flexes the hand at the wrist (fig. 9.29).

Some of the first signs of Parkinson disease appear in the hands. In this disorder, certain brain cells degenerate and damage nerve cells that control muscles. Once called "shaking palsy," the disease often begins with a hand tremor that resembles the motion of rolling a marble between the thumb and forefinger. Another sign is called "cogwheel rigidity." When a doctor rotates the patient's hand in an arc, the hand resists the movement and then jerks, like the cogs in a gear.

The **flexor digitorum profundus** (flek′sor dij″ĭ-to′rum pro-fun′dus) is a large muscle that connects the ulna to the distal phalanges. It flexes the distal joints of the fingers, as when a fist is made (fig. 9.31).

The **flexor digitorum superficialis** (flek′sor dij″ĭ-to′rum su″per-fish″e-a′lis) is a large muscle located beneath the flexor carpi ulnaris. It arises by three heads—one from the medial epicondyle of the humerus, one from the medial side of the ulna, and one from the radius. It is inserted in the tendons of the fingers and flexes the fingers and, by a combined action, flexes the hand at the wrist (fig. 9.29).

Extensors

The **extensor carpi radialis longus** (eks-ten′sor kar-pi′ ra″de-a′lis long′gus) runs along the lateral side of the forearm, connecting the humerus to the hand. It extends the hand at the wrist and assists in abducting the hand (figs. 9.30 and 9.31).

The **extensor carpi radialis brevis** (eks-ten′sor kar-pi′ ra″de-a′lis brev′ĭs) is a companion of the extensor carpi radialis longus and is located medially to it. This muscle runs from the humerus to metacarpal bones and extends the hand at the wrist. It also assists in abducting the hand (figs. 9.30 and 9.31).

The **extensor carpi ulnaris** (eks-ten′sor kar-pi′ ul-na′ris) is located along the posterior surface of the ulna and connects the humerus to the hand. It extends the hand at the wrist and assists in adducting it (figs. 9.30 and 9.31).

The **extensor digitorum** (eks-ten′sor dij″ĭ-to rum) runs medially along the back of the forearm. It connects the humerus to the posterior surface of the phalanges and extends the fingers (figs. 9.30 and 9.31).

A structure called the *extensor retinaculum* consists of a group of heavy connective tissue fibers in the fascia of the wrist (fig. 9.30). It connects the lateral margin of the radius with the medial border of the styloid process of the ulna and certain bones of the wrist. The retinaculum gives off branches of connective tissue to the underlying wrist bones, creating a series of sheathlike compartments through which the tendons of the extensor muscles pass to the wrist and fingers.

Muscles of the Abdominal Wall

The walls of the chest and pelvic regions are supported directly by bone, but those of the abdomen are not. Instead, the anterior and lateral walls of the abdomen are composed of layers of broad, flattened muscles. These muscles connect the rib cage and vertebral column to the pelvic girdle. A band of tough connective tissue, called the **linea alba** (lin′e-ah al′bah), extends from the xiphoid process of the sternum to the symphysis pubis. It is an attachment for some of the abdominal wall muscles.

Contraction of these muscles decreases the volume of the abdominal cavity and increases the pressure inside. This action helps force air out of the lungs during forceful exhalation and also aids in defecation, urination, vomiting, and childbirth.

The abdominal wall muscles are shown in figure 9.32, reference plate 62, and are listed in table 9.10. They include the following:

External oblique	Transversus abdominis
Internal oblique	Rectus abdominis

TABLE 9.10 Muscles of the Abdominal Wall

Muscle	Origin	Insertion	Action	Nerve Supply
External oblique	Outer surfaces of lower ribs	Outer lip of iliac crest and linea alba	Tenses abdominal wall and compresses abdominal contents	Intercostal nerves 7–12
Internal oblique	Crest of ilium and inguinal ligament	Cartilages of lower ribs, linea alba, and crest of pubis	Same as above	Intercostal nerves 7–12
Transversus abdominis	Costal cartilages of lower ribs, processes of lumbar vertebrae, lip of iliac crest, and inguinal ligament	Linea alba and crest of pubis	Same as above	Intercostal nerves 7–12
Rectus abdominis	Crest of pubis and symphysis pubis	Xiphoid process of sternum and costal cartilages	Same as above; also flexes vertebral column	Intercostal nerves 7–12

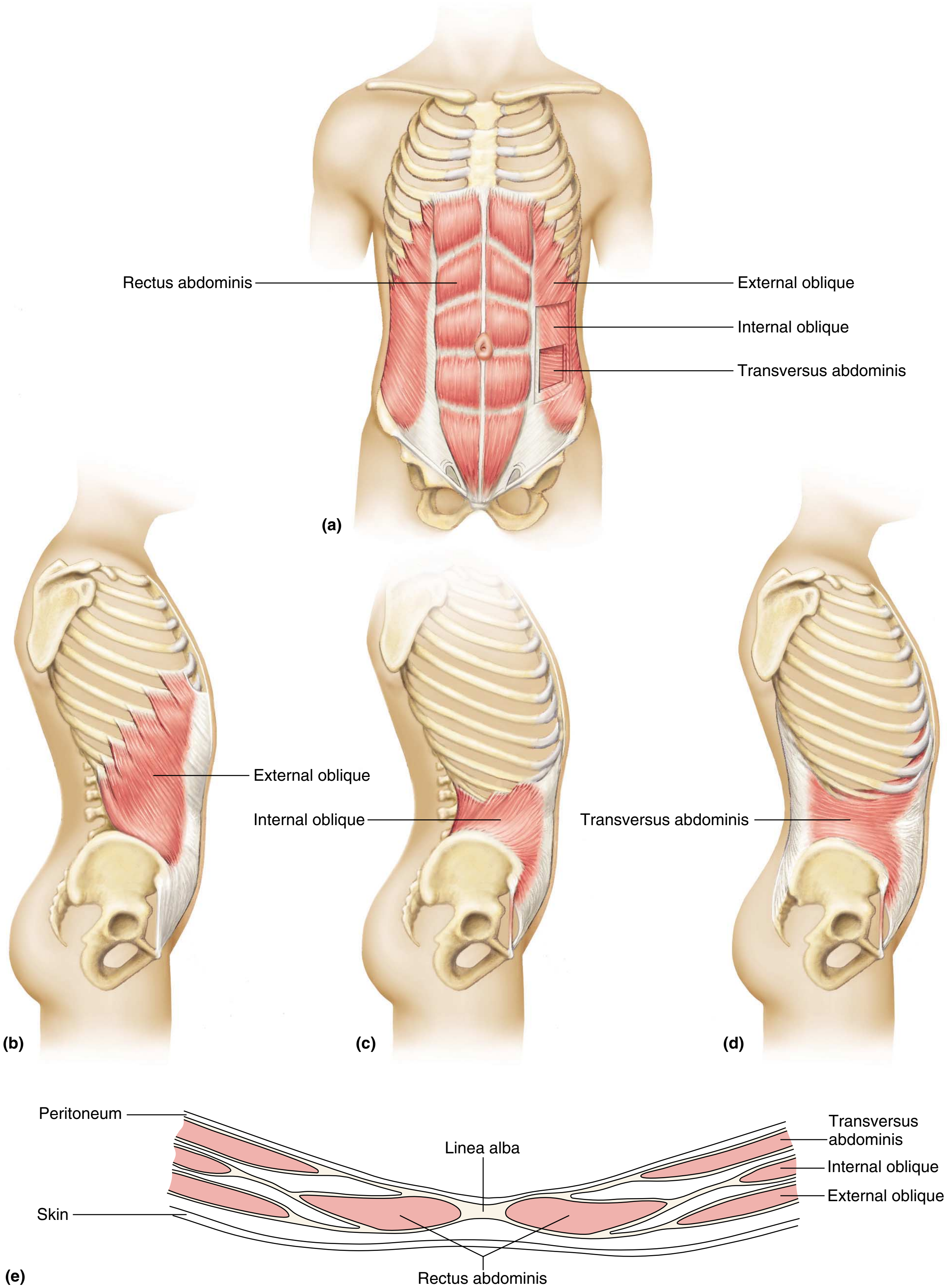


FIGURE 9.32

Muscles of the abdominal wall. (*a–d*) Isolated muscles of the abdominal wall. (*e*) Transverse section through the abdominal wall.

The **external oblique** (eks-ter′nal ŏ-blēk) is a broad, thin sheet of muscle whose fibers slant downward from the lower ribs to the pelvic girdle and the linea alba. When this muscle contracts, it tenses the abdominal wall and compresses the contents of the abdominal cavity.

Similarly, the **internal oblique** (in-ter′nal ŏ-blēk) is a broad, thin sheet of muscle located beneath the external oblique. Its fibers run up and forward from the pelvic girdle to the lower ribs. Its function is similar to that of the external oblique.

The **transversus abdominis** (trans-ver′sus ab-dom′ĭ-nis) forms a third layer of muscle beneath the external and internal obliques. Its fibers run horizontally from the lower ribs, lumbar vertebrae, and ilium to the linea alba and pubic bones. It functions in the same manner as the external and internal obliques.

The **rectus abdominis** (rek′tus ab-dom′ĭ-nis) is a long, straplike muscle that connects the pubic bones to the ribs and sternum. Three or more fibrous bands cross the muscle transversely, giving it a segmented appearance. The muscle functions with other abdominal wall muscles to compress the contents of the abdominal cavity, and it also helps to flex the vertebral column.

Muscles of the Pelvic Outlet

Two muscular sheets span the outlet of the pelvis—a deeper **pelvic diaphragm** and a more superficial **urogenital diaphragm.** The pelvic diaphragm forms the floor of the pelvic cavity, and the urogenital diaphragm fills the space within the pubic arch. Figure 9.33 and table 9.11 show the muscles of the male and female pelvic outlets. They include the following:

Pelvic Diaphragm	**Urogenital Diaphragm**
Levator ani	Superficial transversus perinei
Coccygeus	Bulbospongiosus
	Ischiocavernosus
	Sphincter urethrae

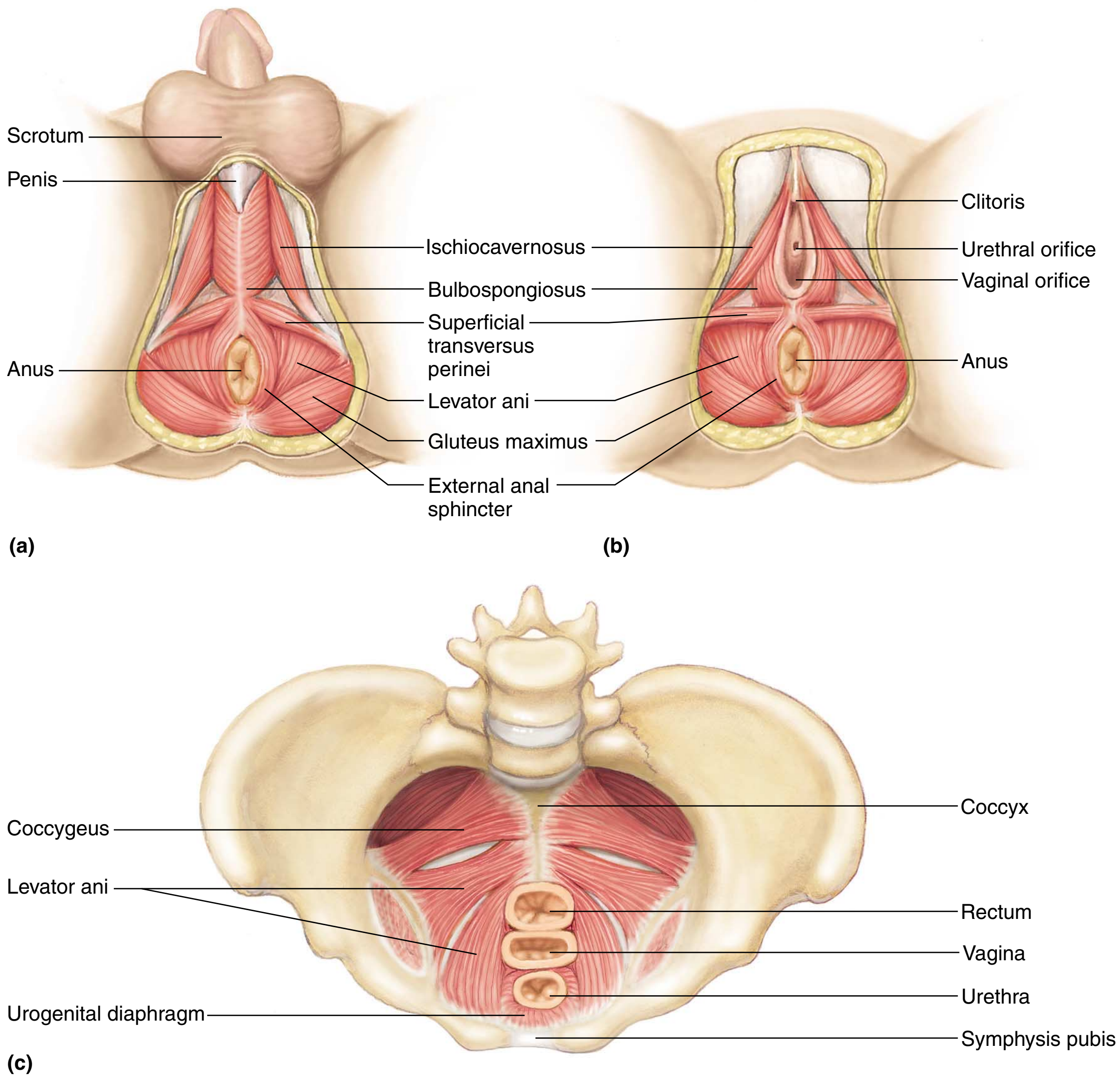


FIGURE 9.33

External view of muscles of (*a*) the male pelvic outlet and (*b*) the female pelvic outlet. (*c*) Internal view of female pelvic and urogenital diaphragms.

TABLE 9.11 Muscles of the Pelvic Outlet

Muscle	Origin	Insertion	Action	Nerve Supply
Levator ani	Pubic bone and ischial spine	Coccyx	Supports pelvic viscera and provides sphincterlike action in anal canal and vagina	Pudendal n.
Coccygeus	Ischial spine	Sacrum and coccyx	Same as above	S4 and S5 nerves
Superficial transversus perinei	Ischial tuberosity	Central tendon	Supports pelvic viscera	Pudendal n.
Bulbospongiosus	Central tendon	Males: Urogenital diaphragm and fascia of penis Females: Pubic arch and root of clitoris	Males: Assists emptying of urethra Females: Constricts vagina	Pudendal n.
Ischiocavernosus	Ischial tuberosity	Pubic arch	Assists function of bulbospongiosus	Pudendal n.
Sphincter urethrae	Margins of pubis and ischium	Fibers of each unite with those from other side	Opens and closes urethra	Pudendal n.

Pelvic Diaphragm

The **levator ani** (le-va′tor ah-ni′) muscles form a thin sheet across the pelvic outlet. They are connected at the midline posteriorly by a ligament that extends from the tip of the coccyx to the anal canal. Anteriorly, they are separated in the male by the urethra and the anal canal, and in the female by the urethra, vagina, and anal canal. These muscles help support the pelvic viscera and provide sphincterlike action in the anal canal and vagina.

An *external anal sphincter* that is under voluntary control and an *internal anal sphincter* that is formed of involuntary muscle fibers of the intestine encircle the anal canal and keep it closed.

The **coccygeus** (kok-sij′e-us) is a fan-shaped muscle that extends from the ischial spine to the coccyx and sacrum. It aids the levator ani.

Urogenital Diaphragm

The **superficial transversus perinei** (su″per-fish′al trans-ver′sus per″ĭ-ne′i) consists of a small bundle of muscle fibers that passes medially from the ischial tuberosity along the posterior border of the urogenital diaphragm. It assists other muscles in supporting the pelvic viscera.

In males, the **bulbospongiosus** (bul″bo-spon″je-o′sus) muscles are united surrounding the base of the penis. They assist in emptying the urethra. In females, these muscles are separated medially by the vagina and constrict the vaginal opening. They can also retard the flow of blood in veins, which helps maintain an erection in the penis of the male and in the clitoris of the female.

The **ischiocavernosus** (is″ke-o-kav″er-no′sus) muscle is a tendinous structure that extends from the ischial tuberosity to the margin of the pubic arch. It assists the bulbospongiosus muscle.

The **sphincter urethrae** (sfingk′ter u-re′thrē) are muscles that arise from the margins of the pubic and ischial bones. Each arches around the urethra and unites with the one on the other side. Together they act as a sphincter that closes the urethra by compression and opens it by relaxation, thus helping control the flow of urine.

Muscles That Move the Thigh

The muscles that move the thigh are attached to the femur and to some part of the pelvic girdle. (An important exception is the sartorius, described later.) They can be separated into anterior and posterior groups. The muscles of the anterior group primarily flex the thigh; those of the posterior group extend, abduct, or rotate it. The muscles in these groups are shown in figures 9.34, 9.35, 9.36, 9.37, in reference plates 66 and 67, and are listed in table 9.12. Muscles that move the thigh include the following:

Anterior Group	**Posterior Group**
Psoas major	Gluteus maximus
Iliacus	Gluteus medius
	Gluteus minimus
	Tensor fasciae latae

Still another group of muscles, attached to the femur and pelvic girdle, adducts the thigh. This group includes the following:

Pectineus	Adductor magnus
Adductor longus	Gracilis

Anterior Group

The **psoas** (so′as) **major** is a long, thick muscle that connects the lumbar vertebrae to the femur. It flexes the thigh (fig. 9.34).

The **iliacus** (il′e-ak-us), a large, fan-shaped muscle, lies along the lateral side of the psoas major. The iliacus and the psoas major are the primary flexors of the thigh, and they advance the lower limb in walking movements (fig. 9.34).

Posterior Group

The **gluteus maximus** (gloo′te-us mak′si-mus) is the largest muscle in the body and covers a large part of each buttock. It connects the ilium, sacrum, and coccyx to the

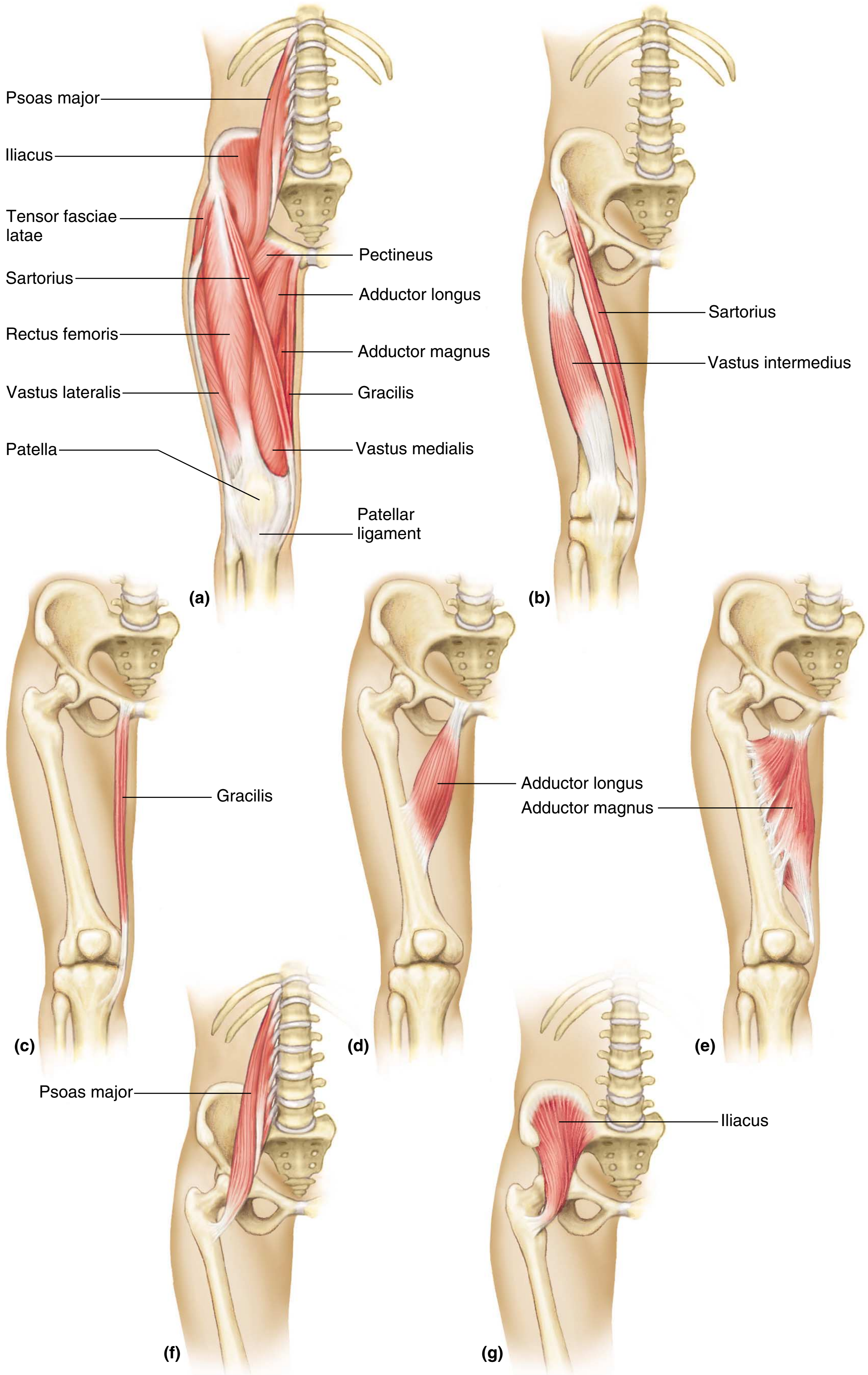


FIGURE 9.34

Muscles of the thigh and leg. (*a*) Muscles of the anterior right thigh. Isolated views of (*b*) the vastus intermedius, (*c–e*) adductors of the thigh, (*f–g*) flexors of the thigh.

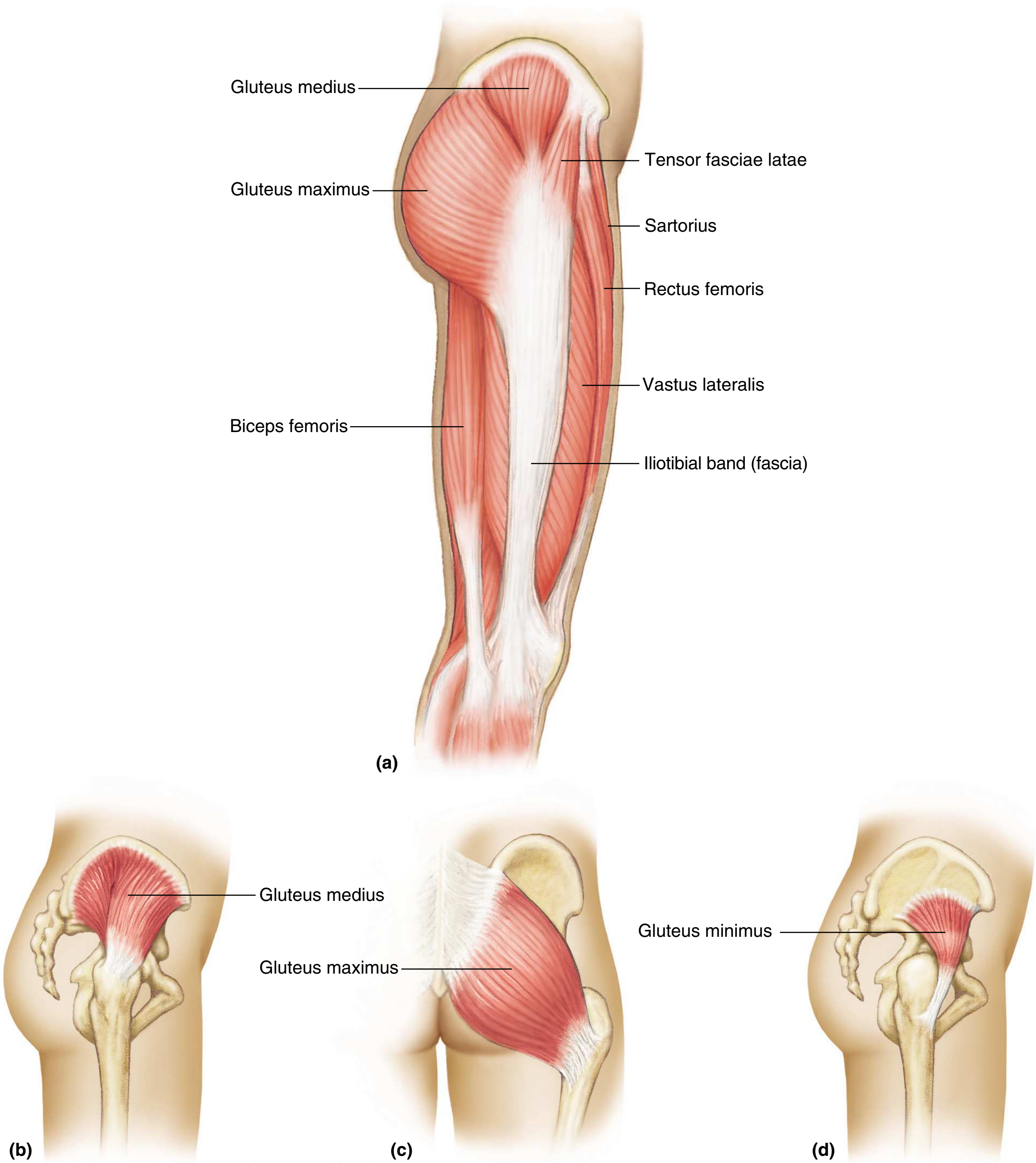


FIGURE 9.35
Muscles of the thigh and leg. (*a*) Muscles of the lateral right thigh. (*b–d*) Isolated views of the gluteal muscles.

femur by fascia of the thigh and extends the thigh. The gluteus maximus helps to straighten the lower limb at the hip when a person walks, runs, or climbs. It is also used to raise the body from a sitting position (fig. 9.35).

The **gluteus medius** (gloo′te-us me′de-us) is partly covered by the gluteus maximus. Its fibers extend from the ilium to the femur, and they abduct the thigh and rotate it medially (fig. 9.35).

The **gluteus minimus** (gloo′te-us min′ĭ-mus) lies beneath the gluteus medius and is its companion in attachments and functions (fig. 9.35).

The **tensor fasciae latae** (ten′sor fash′e-e lah-tē) connects the ilium to the iliotibial band (fascia of the thigh), which continues downward to the tibia. This muscle abducts and flexes the thigh and rotates it medially (fig. 9.35).

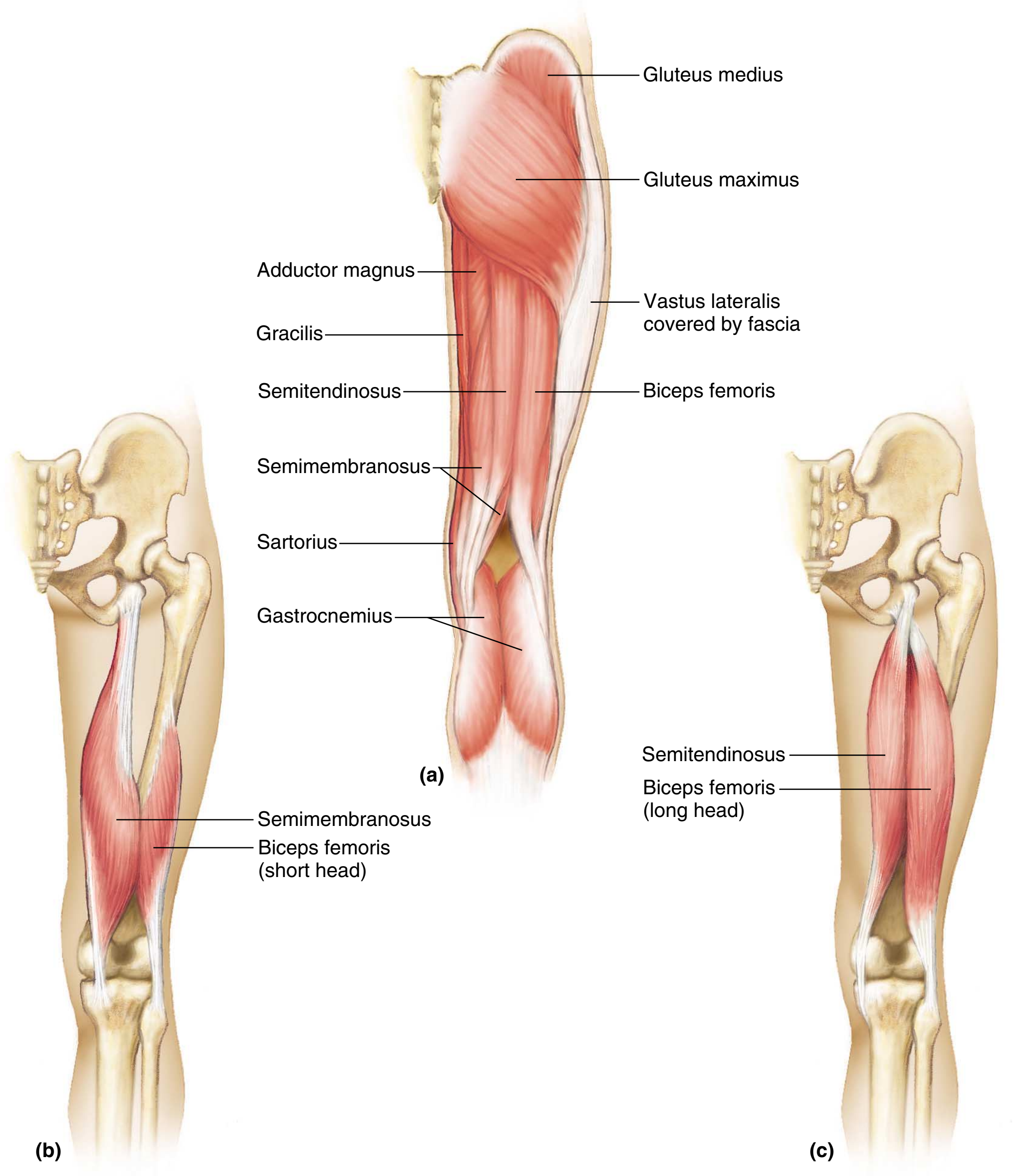


FIGURE 9.36
Muscles of the thigh and leg.
(*a*) Muscles of the posterior right thigh.
(*b* and *c*) Isolated views of muscles that flex the leg at the knee.

The gluteus medius and gluteus minimus help support and maintain the normal position of the pelvis. If these muscles are paralyzed as a result of injury or disease, the pelvis tends to drop to one side whenever the foot on that side is raised. Consequently, the person walks with a waddling limp called the *gluteal gait.*

Thigh Adductors

The **pectineus** (pek-tin′e-us) muscle runs from the spine of the pubis to the femur. It adducts and flexes the thigh (fig. 9.34).

The **adductor longus** (ah-duk′tor long′gus) is a long, triangular muscle that runs from the pubic bone to the femur. It adducts the thigh and assists in flexing and rotating it laterally (fig. 9.34).

The **adductor magnus** (ah-duk′tor mag′nus) is the largest adductor of the thigh. It is a triangular muscle that connects the ischium to the femur. It adducts the thigh and assists in extending and rotating it laterally (fig. 9.34).

The **gracilis** (gras′il-is) is a long, straplike muscle that passes from the pubic bone to the tibia. It adducts the thigh and flexes the leg at the knee (fig. 9.34).

Muscles That Move the Leg

The muscles that move the leg connect the tibia or fibula to the femur or to the pelvic girdle. They fall into two major groups—those that flex the knee and those that extend it. The muscles of these groups are shown in figures 9.34, 9.35, 9.36, 9.37, in reference plates 66 and 67,

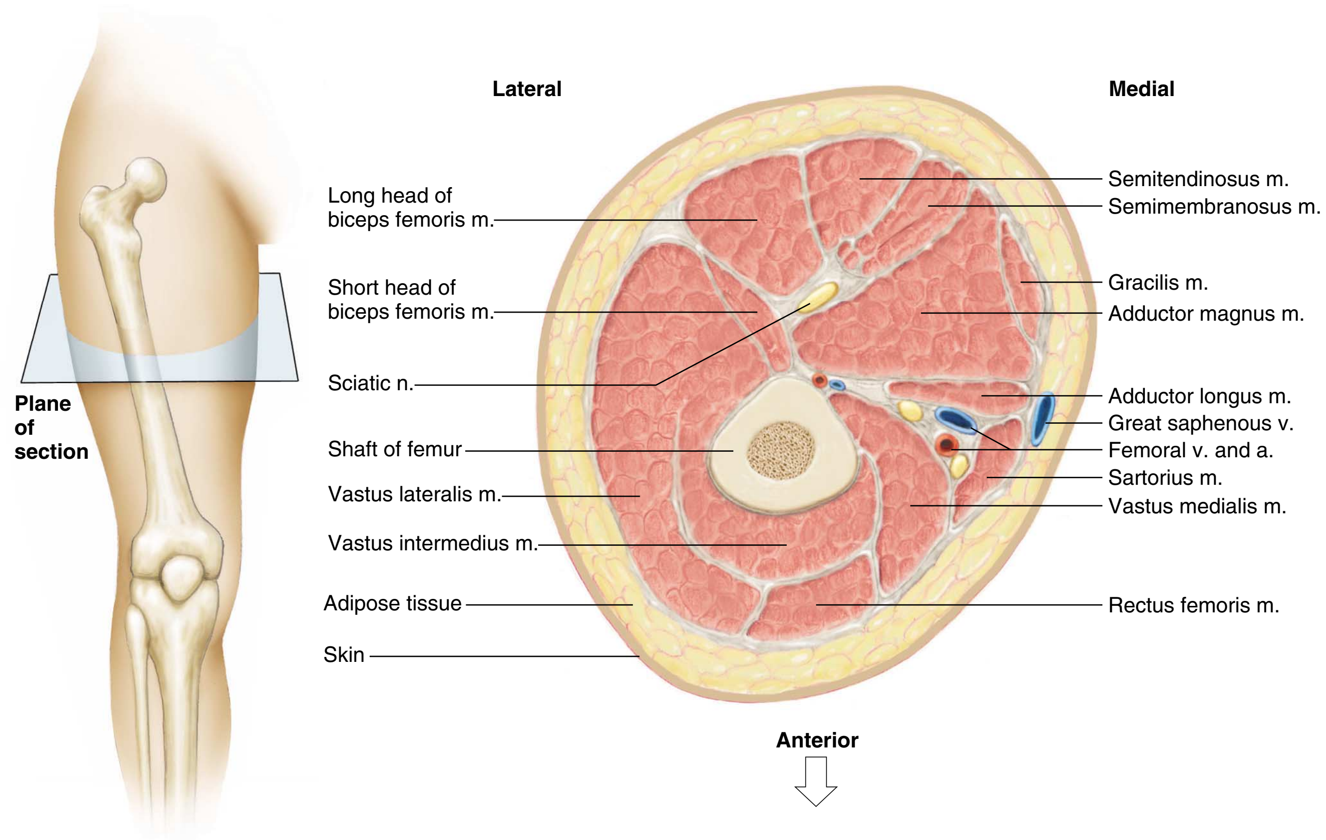


FIGURE 9.37
A cross section of the thigh (superior view).

TABLE 9.12 Muscles That Move the Thigh

Muscle	Origin	Insertion	Action	Nerve Supply
Psoas major	Lumbar intervertebral discs; bodies and transverse processes of lumbar vertebrae	Lesser trochanter of femur	Flexes thigh	Branches of L1-3 nerves
Iliacus	Iliac fossa of ilium	Lesser trochanter of femur	Flexes thigh	Femoral n.
Gluteus maximus	Sacrum, coccyx, and posterior surface of ilium	Posterior surface of femur and fascia of thigh	Extends thigh at hip	Inferior gluteal n.
Gluteus medius	Lateral surface of ilium	Greater trochanter of femur	Abducts and rotates thigh medially	Superior gluteal n.
Gluteus minimus	Lateral surface of ilium	Greater trochanter of femur	Same as gluteus medius	Superior gluteal n.
Tensor fasciae latae	Anterior iliac crest	Iliotibial band (fascia of thigh)	Abducts, flexes, and rotates thigh medially	Superior gluteal n.
Pectineus	Spine of pubis	Femur distal to lesser trochanter	Adducts and flexes thigh	Obturator and femoral nerves
Adductor longus	Pubic bone near symphysis pubis	Posterior surface of femur	Adducts, flexes, and rotates thigh laterally	Obturator n.
Adductor magnus	Ischial tuberosity	Posterior surface of femur	Adducts, extends, and rotates thigh laterally	Obturator and branch of sciatic n.
Gracilis	Lower edge of symphysis pubis	Medial surface of tibia	Adducts thigh and flexes leg at the knee	Obturator n.

TABLE 9.13 Muscles That Move the Leg				
Muscle	**Origin**	**Insertion**	**Action**	**Nerve Supply**
Hamstring Group				
Biceps femoris	Ischial tuberosity and linea aspera of femur	Head of fibula and lateral condyle of tibia	Flexes and rotates leg laterally and extends thigh	Tibial n.
Semitendinosus	Ischial tuberosity	Medial surface of tibia	Flexes and rotates leg medially and extends thigh	Tibial n.
Semimembranosus	Ischial tuberosity	Medial condyle of tibia	Flexes and rotates leg medially and extends thigh	Tibial n.
Sartorius	Anterior superior iliac spine	Medial surface of tibia	Flexes leg and thigh, abducts and rotates thigh laterally	Femoral n.
Quadriceps Femoris Group				
Rectus femoris	Spine of ilium and margin of acetabulum			
Vastus lateralis	Greater trochanter and posterior surface of femur	Patella by common tendon, which continues as patellar ligament to tibial tuberosity	Extends leg at knee	Femoral n.
Vastus medialis	Medial surface of femur			
Vastus intermedius	Anterior and lateral surfaces of femur			

and are listed in table 9.13. Muscles that move the leg include the following:

Flexors	**Extensor**
Biceps femoris	Quadriceps femoris group
Semitendinosus	
Semimembranosus	
Sartorius	

Flexors

As its name implies, the **biceps femoris** (bi′seps fem′or-is) has two heads, one attached to the ischium and the other attached to the femur. This muscle passes along the back of the thigh on the lateral side and connects to the proximal ends of the fibula and tibia. The biceps femoris is one of the hamstring muscles, and its tendon (hamstring) can be felt as a lateral ridge behind the knee. This muscle flexes and rotates the leg laterally and extends the thigh (figs. 9.35 and 9.36).

The **semitendinosus** (sem″e-ten′dĭ-no-sus) is another hamstring muscle. It is a long, bandlike muscle on the back of the thigh toward the medial side, connecting the ischium to the proximal end of the tibia. The semitendinosus is so named because it becomes tendinous in the middle of the thigh, continuing to its insertion as a long, cordlike tendon. It flexes and rotates the leg medially and extends the thigh (fig. 9.36).

The **semimembranosus** (sem″e-mem′brah-no-sus) is the third hamstring muscle and is the most medially located muscle in the back of the thigh. It connects the ischium to the tibia and flexes and rotates the leg medially and extends the thigh (fig. 9.36).

The **sartorius** (sar-to′re-us) is an elongated, straplike muscle that passes obliquely across the front of the thigh and then descends over the medial side of the knee. It connects the ilium to the tibia and flexes the leg and the thigh. It can also abduct the thigh and rotate it laterally (figs. 9.34 and 9.35).

The tendinous attachments of the hamstring muscles to the ischial tuberosity are sometimes torn as a result of strenuous running or kicking motions. This painful injury is commonly called “pulled hamstrings” and is usually accompanied by internal bleeding from damaged blood vessels that supply the muscles.

Extensor

The large, fleshy muscle group called the **quadriceps femoris** (kwod′rĭ-spes fem′or-is) occupies the front and sides of the thigh and is the primary extensor of the knee. It is composed of four parts—*rectus femoris, vastus lateralis, vastus medialis,* and *vastus intermedius* (figs. 9.34 and 9.37). These parts connect the ilium and femur to a common *patellar tendon,* which passes over the front of the knee and attaches to the patella. This tendon then continues as the *patellar ligament* to the tibia.

Occasionally, as a result of traumatic injury in which muscle, such as the quadriceps femoris, is compressed against an underlying bone, new bone tissue may begin to develop within the damaged muscle. This condition is called *myositis ossificans.* When the bone tissue matures several months following the injury, surgery can remove the newly formed bone.

Muscles That Move the Foot

Movements of the foot include movements of the ankle and toes. A number of muscles that move the foot are located in the leg. They attach the femur, tibia, and fibula to bones of the foot and are responsible for moving the foot upward (dorsiflexion) or downward (plantar flexion) and turning the foot so the toes are inward (inversion) or outward (eversion). These muscles are shown in figures 9.38, 9.39, 9.40, 9.41, in reference plates 68, 69, 70, and are listed in table 9.14. Muscles that move the foot include the following:

Dorsal Flexors
Tibialis anterior
Fibularis tertius
Extensor digitorum longus

Invertor
Tibialis posterior

Plantar Flexors
Gastrocnemius
Soleus
Flexor digitorum longus

Evertor
Fibularis longus

Dorsal Flexors

The **tibialis anterior** (tib″e-a′lis an-te′re-or) is an elongated, spindle-shaped muscle located on the front of the leg. It arises from the surface of the tibia, passes medially over the distal end of the tibia, and attaches to bones of the foot. Contraction of the tibialis anterior causes dorsiflexion and inversion of the foot (fig. 9.38).

The **fibularis** (peroneus) **tertius** (fib″u-la′ris ter′shus) is a muscle of variable size that connects the fibula to the lateral side of the foot. It functions in dorsiflexion and eversion of the foot (fig. 9.38).

The **extensor digitorum longus** (eks-ten′sor dij″ĭ-to′rum long′gus) is situated along the lateral side of the leg just behind the tibialis anterior. It arises from the proximal end of the tibia and the shaft of the fibula. Its tendon divides into four parts as it passes over the front of the ankle. These parts continue over the surface of the foot and attach to the four lateral toes. The actions of the extensor digitorum longus include dorsiflexion of the foot, eversion of the foot, and extension of the toes (figs. 9.38 and 9.39).

Plantar Flexors

The **gastrocnemius** (gas″trok-ne′me-us) on the back of the leg forms part of the calf. It arises by two heads from the femur. The distal end of this muscle joins the strong *calcaneal tendon* (Achilles tendon), which descends to the heel and attaches to the calcaneus. The gastrocnemius is a powerful plantar flexor of the foot that aids in pushing the body forward when a person walks or runs. It also flexes the leg at the knee (figs. 9.39 and 9.40).

TABLE 9.14 Muscles That Move the Foot

Muscle	Origin	Insertion	Action	Nerve Supply
Tibialis anterior	Lateral condyle and lateral surface of tibia	Tarsal bone (cuneiform) and first metatarsal	Dorsiflexion and inversion of foot	Deep fibular n.
Fibularis tertius	Anterior surface of fibula	Dorsal surface of fifth metatarsal	Dorsiflexion and eversion of foot	Deep fibular n.
Extensor digitorum longus	Lateral condyle of tibia and anterior surface of fibula	Dorsal surfaces of second and third phalanges of four lateral toes	Dorsiflexion and eversion of foot and extension of toes	Deep fibular n.
Gastrocnemius	Lateral and medial condyles of femur	Posterior surface of calcaneus	Plantar flexion of foot and flexion of leg at knee	Tibial n.
Soleus	Head and shaft of fibula and posterior surface of tibia	Posterior surface of calcaneus	Plantar flexion of foot	Tibial n.
Flexor digitorum longus	Posterior surface of tibia	Distal phalanges of four lateral toes	Plantar flexion and inversion of foot and flexion of four lateral toes	Tibial n.
Tibialis posterior	Lateral condyle and posterior surface of tibia and posterior surface of fibula	Tarsal and metatarsal bones	Plantar flexion and inversion of foot	Tibial n.
Fibularis longus	Lateral condyle of tibia and head and shaft of fibula	Tarsal and metatarsal bones	Plantar flexion and eversion of foot; also supports arch	Superficial fibular n.

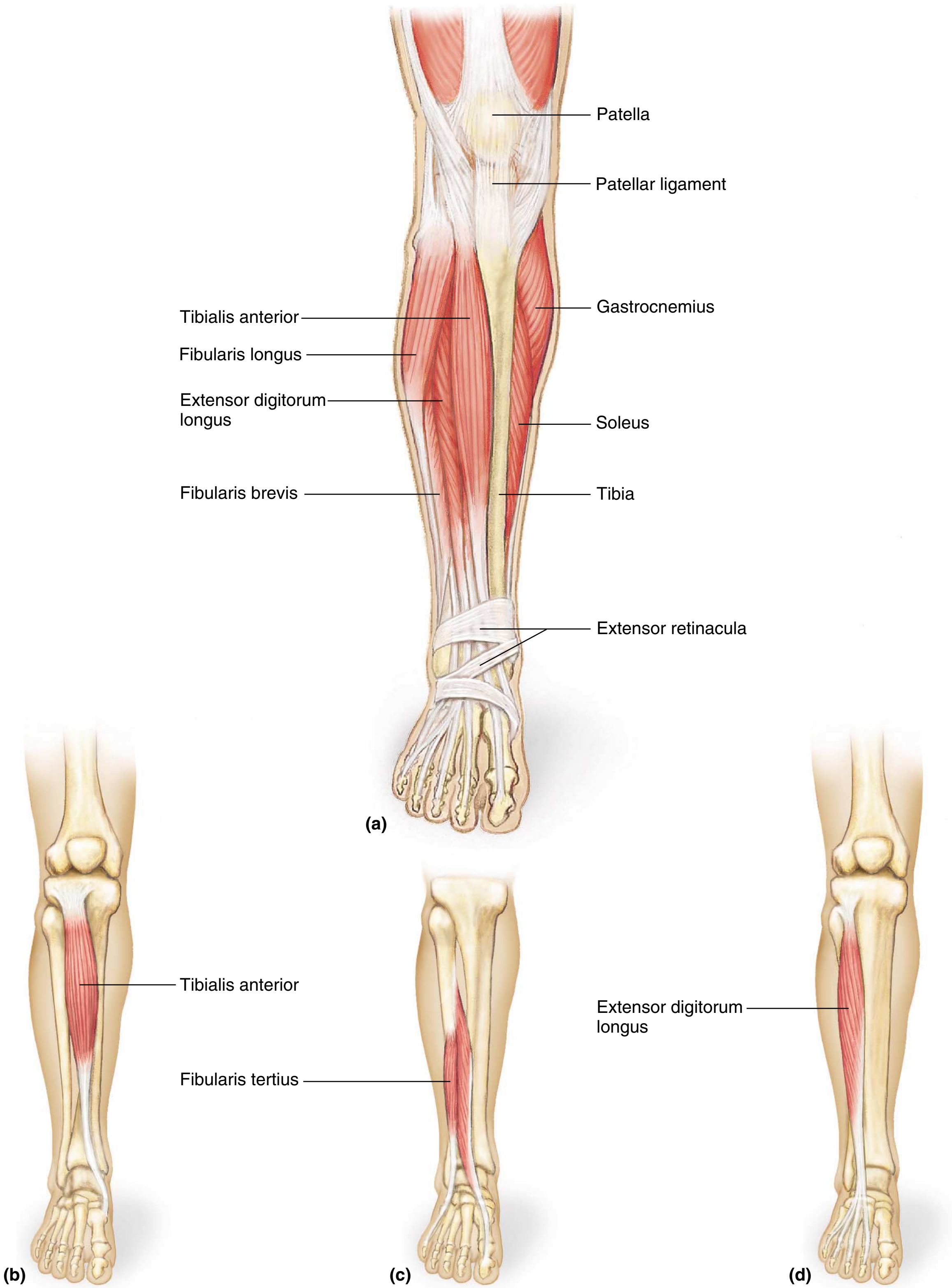


FIGURE 9.38
Muscles of the leg. (*a*) Muscles of the anterior right leg. (*b*–*d*) Isolated views of muscles associated with the anterior right leg.

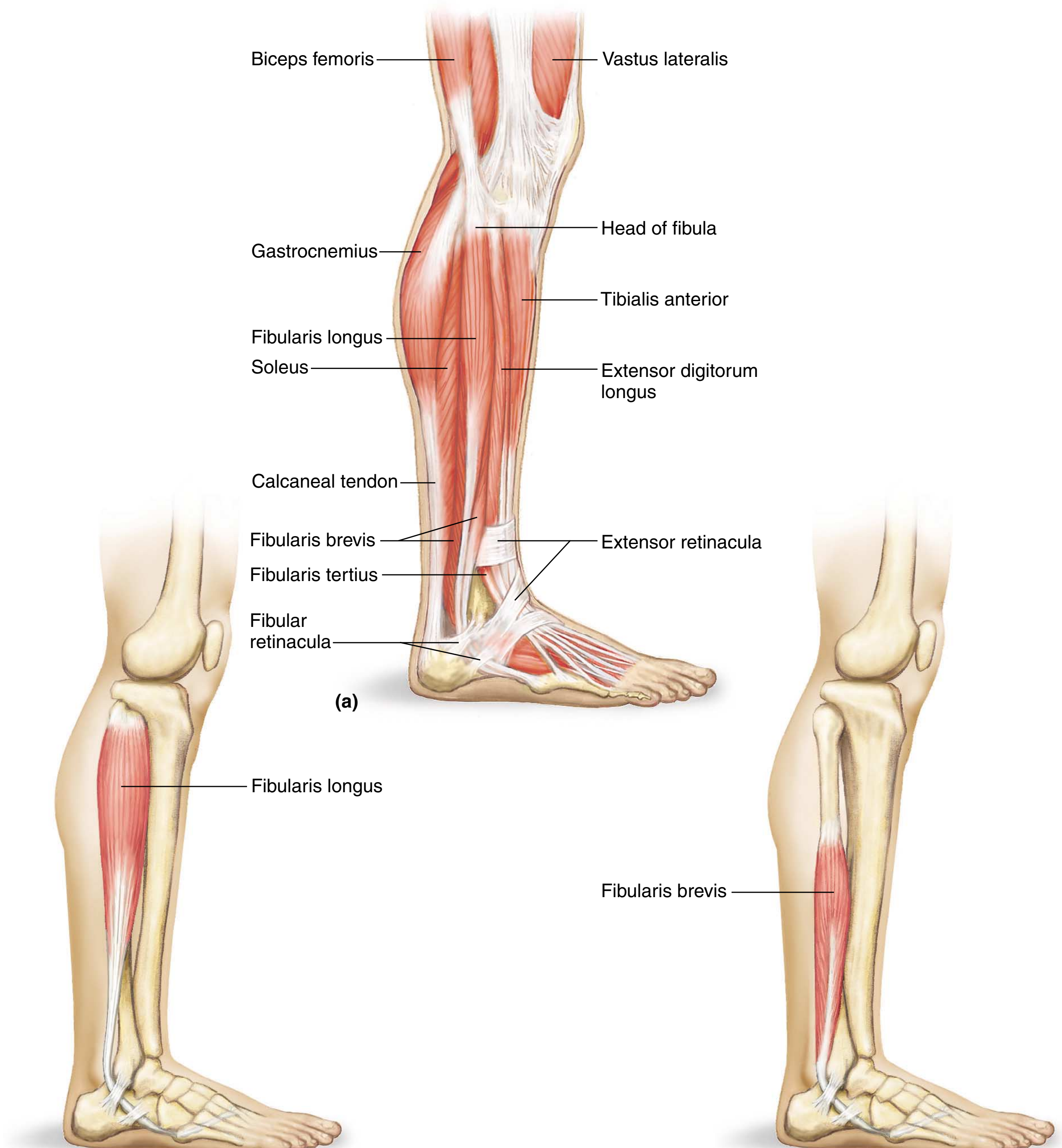


FIGURE 9.39
Muscles of the leg. (*a*) Muscles of the lateral right leg. Isolated views of (*b*) fibularis longus and (*c*) fibularis brevis.

Strenuous athletic activity may partially or completely tear the calcaneal (Achilles) tendon. This injury occurs most frequently in middle-aged athletes who run or play sports that involve quick movements and directional changes. A torn calcaneal tendon usually requires surgical treatment.

The **soleus** (so′le-us) is a thick, flat muscle located beneath the gastrocnemius, and together these two muscles form the calf of the leg. The soleus arises from the tibia and fibula, and it extends to the heel by way of the calcaneal tendon. It acts with the gastrocnemius to cause plantar flexion of the foot (figs. 9.39 and 9.40).

The **flexor digitorum longus** (flek′sor dij″ĭ-to′rum long′gus) extends from the posterior surface of the tibia to the foot. Its tendon passes along the plantar surface of the foot. There the muscle divides into four parts that attach to the terminal bones of the four lateral toes. This muscle assists in plantar flexion of the foot, flexion of the four lateral toes, and inversion of the foot (fig. 9.40).

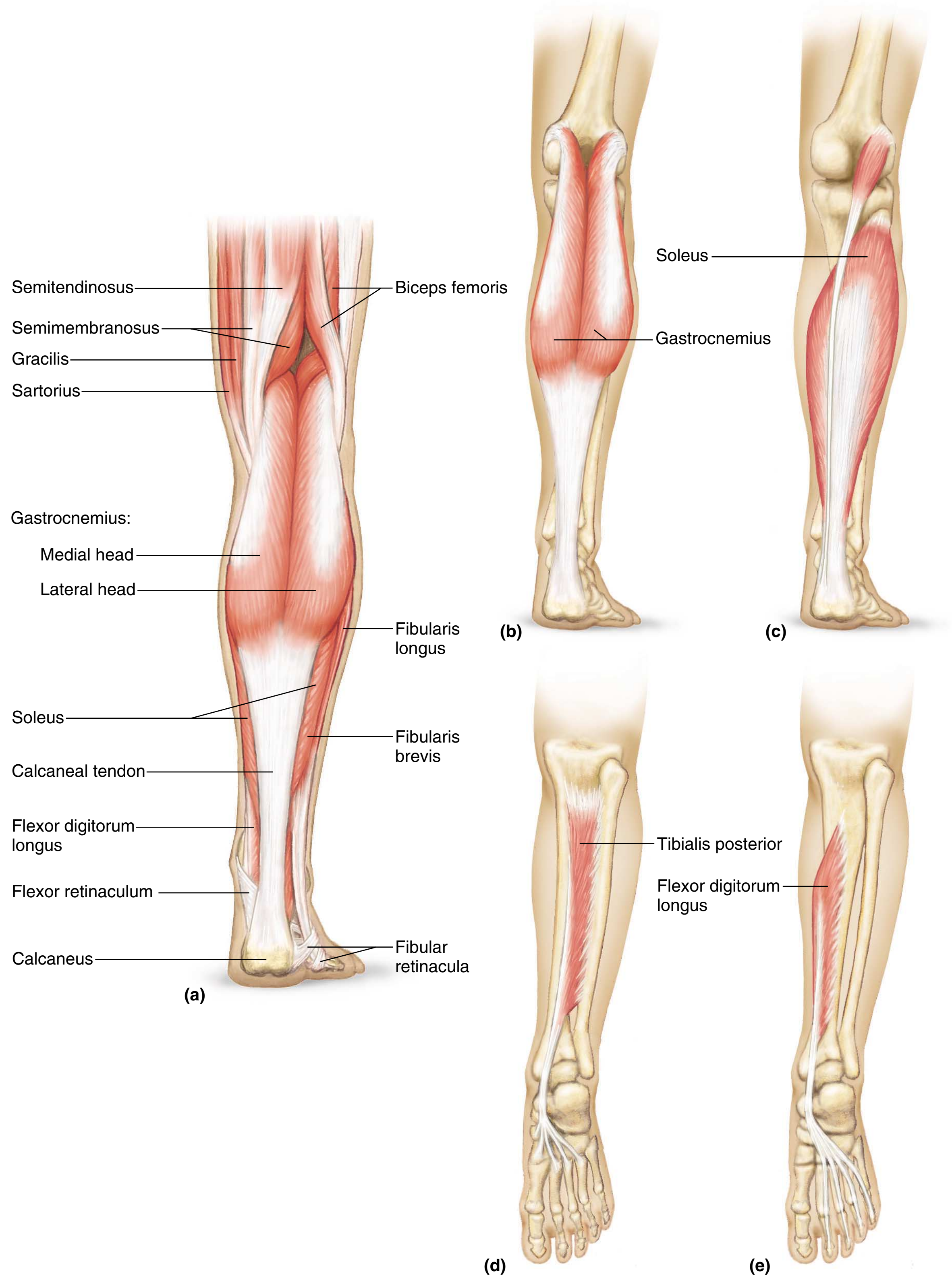


FIGURE 9.40

Muscles of the leg. (*a*) Muscles of the posterior right leg. (*b*–*e*) Isolated views of muscles associated with the posterior right leg.

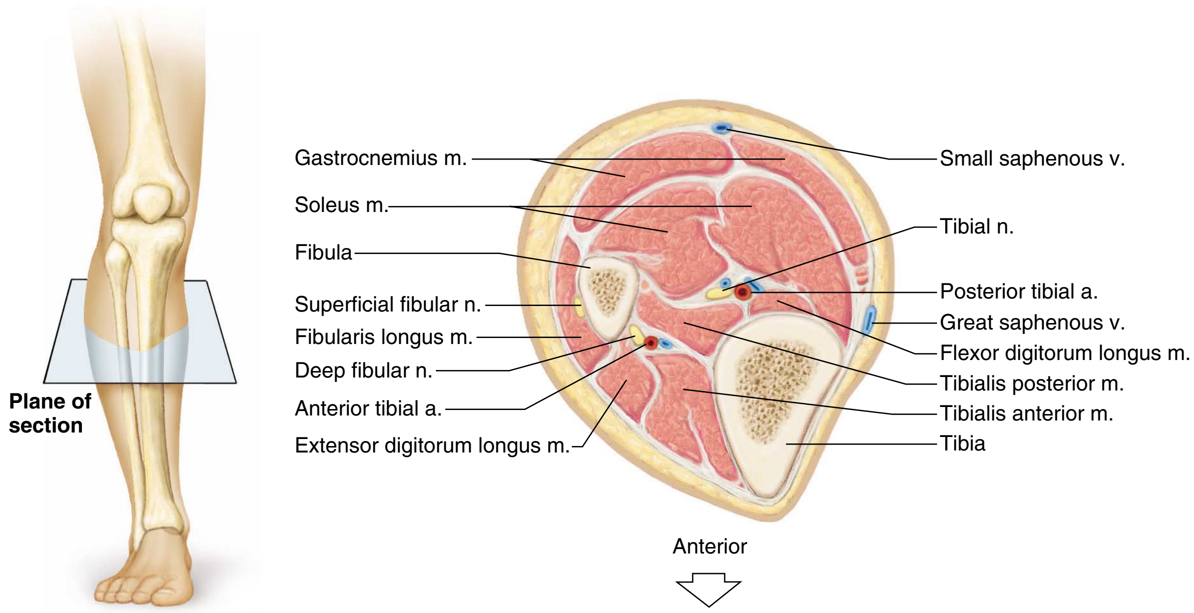


FIGURE 9.41
A cross section of the leg (superior view).

Invertor

The **tibialis posterior** (tib″e-a′lis pos-tēr′e-or) is the deepest of the muscles on the back of the leg. It connects the fibula and tibia to the ankle bones by means of a tendon that curves under the medial malleolus. This muscle assists in inversion and plantar flexion of the foot (fig. 9.40).

Evertor

The **fibularis** (peroneus) **longus** (fib″u-la′ris long′gus) is a long, straplike muscle located on the lateral side of the leg. It connects the tibia and the fibula to the foot by means of a stout tendon that passes behind the lateral malleolus. It everts the foot, assists in plantar flexion, and helps support the arch of the foot (figs. 9.39 and 9.41).

As in the wrist, fascia in various regions of the ankle thicken to form retinacula. Anteriorly, for example, *extensor retinacula* connect the tibia and fibula as well as the calcaneus and fascia of the sole. These retinacula form sheaths for tendons crossing the front of the ankle (fig. 9.39).

Posteriorly, on the inside, a *flexor retinaculum* runs between the medial malleolus and the calcaneus and forms sheaths for tendons passing beneath the foot (fig. 9.40). *Fibular retinacula* connect the lateral malleolus and the calcaneus, providing sheaths for tendons on the lateral side of the ankle (fig. 9.39).

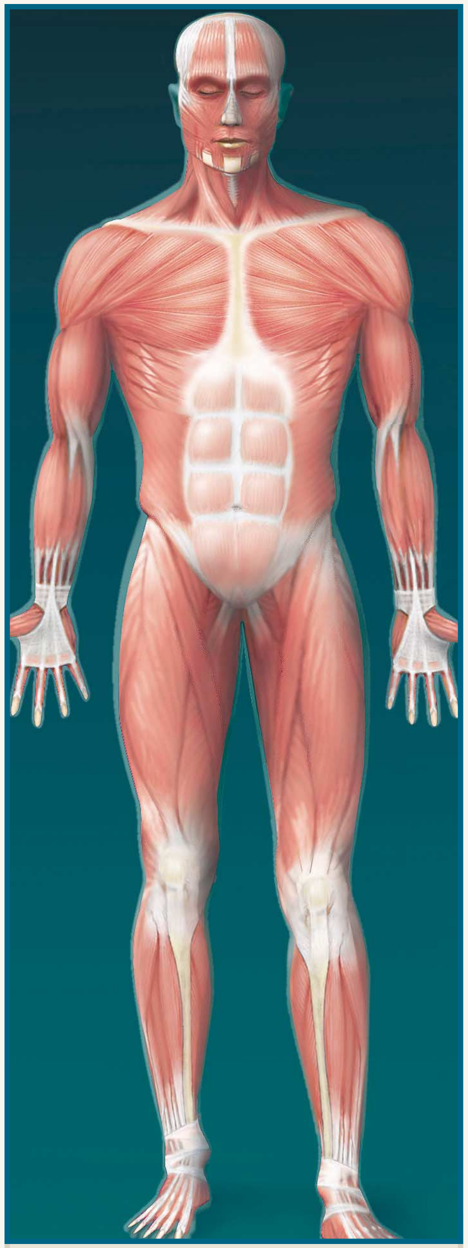
Life-Span Changes

Signs of aging in the muscular system begin to appear in one's forties, although a person can still be very active. At a microscopic level, supplies of the molecules that enable muscles to function—myoglobin, ATP, and creatine phosphate—decline. The diameters of some muscle fibers may shrink, as the muscle layers in the walls of veins thicken, making the vessels more rigid and less elastic. Very gradually, the muscles become smaller, drier, and capable of less forceful contraction. Connective tissue and adipose cells begin to replace some muscle tissue. By age eighty, nearly half the muscle mass has atrophied, due to decline in motor neuron activity. Diminishing muscular strength slows reflexes.

Exercise can help maintain a healthy muscular system, countering the less effective oxygen delivery that results from the decreased muscle mass that accompanies aging. Exercise also maintains the flexibility of blood vessels, which can decrease the likelihood of hypertension developing. A physician should be consulted before starting any exercise program.

According to the National Institute on Aging, exercise should include strength training and aerobics, with stretching before and after. Strength training consists of weight lifting or using a machine that works specific muscles against a resistance, performed so that the same muscle is not exercised on consecutive days. Strength training increases muscle mass, and the resulting stronger muscles can alleviate pressure on the joints, which may lessen arthritis pain. Aerobic exercise improves oxygen utilization by muscles and increases endurance. Stretching increases flexibility and decreases muscle strain, while improving blood flow to all muscles. A side benefit of regular exercise, especially among older individuals is fewer bouts with depression.

1. What changes are associated with an aging muscular system?
2. Describe two types of recommended exercise.



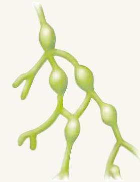
MUSCULAR SYSTEM

Muscles provide the force for moving body parts.

Integumentary System

The skin increases heat loss during skeletal muscle activity. Sensory receptors function in the reflex control of skeletal muscles.

Lymphatic System



Muscle action pumps lymph through lymphatic vessels.

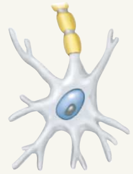
Skeletal System

Bones provide attachments that allow skeletal muscles to cause movement.

Digestive System

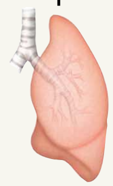
Skeletal muscles are important in swallowing. The digestive system absorbs needed nutrients.

Nervous System



Neurons control muscle contractions.

Respiratory System



Breathing depends on skeletal muscles. The lungs provide oxygen for muscle cells and excrete carbon dioxide.

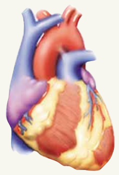
Endocrine System

Hormones help increase blood flow to exercising skeletal muscles.

Urinary System

Skeletal muscles help control expulsion of urine from the urinary bladder.

Cardiovascular System



Blood flow delivers oxygen and nutrients and removes wastes. Cardiac muscle pumps blood, smooth muscle in vessel walls enables vasoconstriction, vasodilation.

Reproductive System

Skeletal muscles are important in sexual activity.

Clinical Terms Related to the Muscular System

contracture (kon-trak′tūr) Condition in which there is great resistance to the stretching of a muscle.
convulsion (kun-vul′shun) Series of involuntary contractions of various voluntary muscles.
electromyography (e-lek″tro-mi-og′rah-fe) Technique for recording the electrical changes that occur in muscle tissues.
fibrillation (fi″bri-la′shun) Spontaneous contractions of individual muscle fibers, producing rapid and uncoordinated activity within a muscle.
fibrosis (fi-bro′sis) Degenerative disease in which connective tissue with many fibers replaces skeletal muscle tissue.
fibrositis (fi″bro-si′tis) Inflammation of connective tissues with many fibers, especially in the muscle fascia. This disease is also called muscular rheumatism.
muscular dystrophy (mus′ku-lar dis′tro-fe) Progressive muscle weakness and atrophy caused by deficient dystrophin protein.
myalgia (mi-al′je-ah) Pain resulting from any muscular disease or disorder.
myasthenia gravis (mi″as-the′ne-ah grav′is) Chronic disease characterized by muscles that are weak and easily fatigued. It results from the immune system's attack on neuromuscular junctions so that stimuli are not transmitted from motor neurons to muscle fibers.
myokymia (mi″o-ki′me-ah) Persistent quivering of a muscle.
myology (mi-ol′o-je) Study of muscles.
myoma (mi-o′mah) Tumor composed of muscle tissue.
myopathy (mi-op′ah-the) Any muscular disease.
myositis (mi″o-si′tis) Inflammation of skeletal muscle tissue.
myotomy (mi-ot′o-me) Cutting of muscle tissue.
myotonia (mi″o-to′ne-ah) Prolonged muscular spasm.
paralysis (pah-ral′ĭ-sis) Loss of ability to move a body part.
paresis (pah-re′sis) Partial or slight paralysis of the muscles.
shin splints (shin′ splints) Soreness on the front of the leg due to straining the anterior leg muscles, often as a result of walking up and down hills.
torticollis (tor″tĭ-kol′is) Condition in which the neck muscles, such as the sternocleidomastoids, contract involuntarily. It is more commonly called wryneck.

CHAPTER SUMMARY

Introduction (page 278)

The three types of muscle tissue are skeletal, smooth, and cardiac.

Structure of a Skeletal Muscle (page 278)

Skeletal muscles are composed of nervous, vascular, and various connective tissues, as well as skeletal muscle tissue.

1. Connective tissue coverings
   a. Fascia covers each skeletal muscle.
   b. Other connective tissues surround cells and groups of cells within the muscle's structure.
   c. Fascia is part of a complex network of connective tissue that extends throughout the body.
2. Skeletal muscle fibers
   a. Each skeletal muscle fiber is a single muscle cell, which is the unit of contraction.
   b. Muscle fibers are cylindrical cells with many nuclei.
   c. The cytoplasm contains mitochondria, sarcoplasmic reticulum, and myofibrils of actin and myosin.
   d. The arrangement of the actin and myosin filaments causes striations. (I bands, Z lines, A bands, H zone and M line.)
   e. Cross-bridges of myosin filaments form linkages with actin filaments. The reaction between actin and myosin filaments provides the basis for contraction.
   f. When a fiber is at rest, troponin and tropomyosin molecules interfere with linkage formation. Calcium ions remove the inhibition.
   g. Transverse tubules extend from the cell membrane into the cytoplasm and are associated with the cisternae of the sarcoplasmic reticulum.

Skeletal Muscle Contraction (page 282)

Muscle fiber contraction results from a sliding movement of actin and myosin filaments that shortens the muscle fiber.

1. Neuromuscular junction
   a. Motor neurons stimulate muscle fibers to contract.
   b. The motor end plate of a muscle fiber lies on one side of a neuromuscular junction.
   c. One motor neuron and the muscle fibers associated with it constitute a motor unit.
   d. In response to a nerve impulse, the end of a motor nerve fiber secretes a neurotransmitter, which diffuses across the junction and stimulates the muscle fiber.
2. Stimulus for contraction
   a. Muscle fiber is usually stimulated by acetylcholine released from the end of a motor nerve fiber.
   b. Acetylcholinesterase decomposes acetylcholine to prevent continuous stimulation.
   c. Stimulation causes a muscle fiber to conduct an impulse that travels over the surface of the sarcolemma and reaches the deep parts of the fiber by means of the transverse tubules.
3. Excitation contraction coupling
   a. A muscle impulse signals the sarcoplasmic reticulum to release calcium ions.
   b. Linkages form between myosin and actin, and the actin filaments move inward, shortening the sarcomere.

4. The Sliding Filament Theory
   a. The sarcomere, defined by striations, is the functional unit of skeletal muscle.
   b. When thick and thin myofilaments slide past one another, the sarcomeres shorten. The muscle contracts.
5. Cross-bridge cycling
   a. A myosin cross-bridge can attach to an actin binding site and pull on the actin filament. The myosin head can then release the actin and combine with another active binding site farther down the actin filament, and pull again.
   b. The breakdown of ATP releases energy that provides the repetition of the cross-bridge cycle.
6. Relaxation
   a. Acetylcholine remaining in the synapse is rapidly decomposed by acetylcholinesterase, preventing continuous stimulation of a muscle fiber.
   b. The muscle fiber relaxes when calcium ions are transported back into the sarcoplasmic reticulum.
   c. Cross-bridge linkages break and do not re-form—the muscle fiber relaxes.
7. Energy sources for contraction
   a. ATP supplies the energy for muscle fiber contraction.
   b. Creatine phosphate stores energy that can be used to synthesize ATP as it is decomposed.
   c. Active muscles depend upon cellular respiration for energy.
8. Oxygen supply and cellular respiration
   a. Anaerobic reactions of cellular respiration yield few ATP molecules, whereas aerobic reactions of cellular respiration provide many ATP molecules.
   b. Hemoglobin in red blood cells carries oxygen from the lungs to body cells.
   c. Myoglobin in muscle cells stores some oxygen temporarily.
9. Oxygen debt
   a. During rest or moderate exercise, oxygen is sufficient to support the aerobic reactions of cellular respiration.
   b. During strenuous exercise, oxygen deficiency may develop, and lactic acid may accumulate as a result of the anaerobic reactions of cellular respiration.
   c. The amount of oxygen needed to convert accumulated lactic acid to glucose and to restore supplies of ATP and creatine phosphate is called oxygen debt.
10. Muscle fatigue
   a. A fatigued muscle loses its ability to contract.
   b. Muscle fatigue is usually due to the effects of accumulation of lactic acid.
   c. Athletes usually produce less lactic acid than nonathletes because of their increased ability to supply oxygen and nutrients to muscles.
11. Heat production
   a. Muscles represent an important source of body heat.
   b. Most of the energy released by cellular respiration is lost as heat.

Muscular Responses (page 290)

1. Threshold stimulus is the minimal stimulus needed to elicit a muscular contraction.
2. Recording a muscle contraction
   a. A twitch is a single, short contraction of a muscle fiber.
   b. A myogram is a recording of an electrically stimulated isolated muscle pulling a lever.
   c. The latent period is the time between stimulus and responding muscle contraction.
   d. During the refractory period immediately following contraction, a muscle cannot respond.
   e. If a muscle fiber contracts at all, it will contract completely. This has been termed the all-or-none response.
   f. The length to which a muscle is stretched before stimulation affects the force it will develop.
      (1) Normal activities occur at optimal length.
      (2) Too long or too short decreases force.
   g. Sustained contractions are more important than twitch contractions in everyday activities.
3. Summation
   a. A rapid series of stimuli may produce summation of twitches and sustained contraction.
   b. Forceful, sustained contraction without relaxation is a tetanic contraction.
4. Recruitment of motor units
   a. Muscles whose motor units contain small numbers of muscle fibers produce finer movements.
   b. Motor units respond in an all-or-none manner.
   c. At low intensity of stimulation, relatively small numbers of motor units contract.
   d. At increasing intensities of stimulation, other motor units are recruited until the muscle contracts with maximal tension.
5. Sustained contractions
   a. When contractions fuse, the strength of contraction may increase due to recruitment of fibers.
   b. Even when a muscle is at rest, its fibers usually maintain tone—that is, remain partially contracted.
6. Types of contractions
   a. One type of isotonic contraction occurs when a muscle contracts and its ends are pulled closer together. Because shortening occurs, it is called a concentric contraction.
   b. Another type of isotonic contraction occurs when the force a muscle generates is less than that required to move or lift an object. This lengthening contraction is called an eccentric contraction.
   c. When a muscle contracts but its attachments do not move, the contraction is called isometric.
   d. Most body movements involve both isometric and isotonic contractions.
7. Fast and slow twitch muscle fibers
   a. The speed of contraction is related to a muscle's specific function.
   b. Slow-contracting, or red, muscles can generate ATP fast enough to keep up with ATP breakdown and can contract for long periods.
   c. Fast-contracting, or white, muscles have reduced ability to carry on the aerobic reactions of cellular respiration and tend to fatigue relatively rapidly.

Smooth Muscles (page 293)

The contractile mechanisms of smooth and cardiac muscles are similar to those of skeletal muscle.

1. Smooth muscle fibers
   a. Smooth muscle cells contain filaments of myosin and actin.
   b. They lack transverse tubules, and the sarcoplasmic reticula are not well developed.
   c. Types include multiunit smooth muscle and visceral smooth muscle.
   d. Visceral smooth muscle displays rhythmicity.
   e. Peristalsis aids movement of material through hollow organs.

2. Smooth muscle contraction
    a. In smooth muscles, calmodulin binds to calcium ions and activates the contraction mechanism.
    b. Both acetylcholine and norepinephrine are neurotransmitters for smooth muscles.
    c. Hormones and stretching affect smooth muscle contractions.
    d. With a given amount of energy, smooth muscle can maintain a contraction for a longer time than can skeletal muscle.
    e. Smooth muscles can change length without changing tautness.

Cardiac Muscle (page 294)

1. Cardiac muscle contracts for a longer time than skeletal muscle because transverse tubules supply extra calcium ions.
2. Intercalated discs connect the ends of adjacent cardiac muscle cells and hold the cells together.
3. A network of fibers contracts as a unit and responds to stimulation in an all-or-none manner.
4. Cardiac muscle is self-exciting, rhythmic, and remains refractory until a contraction is completed.

Skeletal Muscle Actions (page 296)

1. Origin and insertion
    a. The movable end of attachment of a skeletal muscle to a bone is its insertion, and the immovable end is its origin.
    b. Some muscles have more than one origin or insertion.
2. Interaction of skeletal muscles
    a. Skeletal muscles function in groups.
    b. A prime mover is responsible for most of a movement; synergists aid prime movers; antagonists can resist the movement of a prime mover.
    c. Smooth movements depend upon antagonists giving way to the actions of prime movers.

Major Skeletal Muscles (page 297)

Muscle names often describe sizes, shapes, locations, actions, number of attachments, or direction of fibers.

1. Muscles of facial expression
    a. These muscles lie beneath the skin of the face and scalp and are used to communicate feelings through facial expression.
    b. They include the epicranius, orbicularis oculi, orbicularis oris, buccinator, zygomaticus, and platysma.
2. Muscles of mastication
    a. These muscles are attached to the mandible and are used in chewing.
    b. They include the masseter, temporalis, medial pterygoid, and lateral pterygoid.
3. Muscles that move the head and vertebral column
    a. Muscles in the neck and back move the head.
    b. They include the sternocleidomastoid, splenius capitis, semispinalis capitis, and erector spinae.
4. Muscles that move the pectoral girdle
    a. Most of these muscles connect the scapula to nearby bones and are closely associated with muscles that move the arm.
    b. They include the trapezius, rhomboideus major, levator scapulae, serratus anterior, and pectoralis minor.
5. Muscles that move the arm
    a. These muscles connect the humerus to various regions of the pectoral girdle, ribs, and vertebral column.
    b. They include the coracobrachialis, pectoralis major, teres major, latissimus dorsi, supraspinatus, deltoid, subscapularis, infraspinatus, and teres minor.
6. Muscles that move the forearm
    a. These muscles connect the radius and ulna to the humerus and pectoral girdle.
    b. They include the biceps brachii, brachialis, brachioradialis, triceps brachii, supinator, pronator teres, and pronator quadratus.
7. Muscles that move the hand
    a. These muscles arise from the distal end of the humerus and from the radius and ulna.
    b. They include the flexor carpi radialis, flexor carpi ulnaris, palmaris longus, flexor digitorum profundus, flexor digitorum superficialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, and extensor digitorum.
    c. An extensor retinaculum forms sheaths for tendons of the extensor muscles.
8. Muscles of the abdominal wall
    a. These muscles connect the rib cage and vertebral column to the pelvic girdle.
    b. They include the external oblique, internal oblique, transversus abdominis, and rectus abdominis.
9. Muscles of the pelvic outlet
    a. These muscles form the floor of the pelvic cavity and fill the space of the pubic arch.
    b. They include the levator ani, coccygeus, superficial transversus perinei, bulbospongiosus, ischiocavernosus, and sphincter urethrae.
10. Muscles that move the thigh
    a. These muscles are attached to the femur and to some part of the pelvic girdle.
    b. They include the psoas major, iliacus, gluteus maximus, gluteus medius, gluteus minimus, tensor fasciae latae, pectineus, adductor longus, adductor magnus, and gracilis.
11. Muscles that move the leg
    a. These muscles connect the tibia or fibula to the femur or pelvic girdle.
    b. They include the biceps femoris, semitendinosus, semimembranosus, sartorius, and the quadriceps femoris group.
12. Muscles that move the foot
    a. These muscles attach the femur, tibia, and fibula to various bones of the foot.
    b. They include the tibialis anterior, fibularis tertius, extensor digitorum longus, gastrocnemius, soleus, flexor digitorum longus, tibialis posterior, and fibularis longus.
    c. Retinacula form sheaths for tendons passing to the foot.

Life-Span Changes (page 325)

1. Beginning in one's forties, supplies of ATP, myoglobin, and creatine phosphate begin to decline.
2. By age eighty, muscle mass may be halved. Reflexes slow. Adipose cells and connective tissue replace some muscle tissue.
3. Exercise is very beneficial in maintaining muscle function.

CRITICAL THINKING QUESTIONS

1. Why do you think athletes generally perform better if they warm up by exercising lightly before a competitive event?
2. Following childbirth, a woman may lose urinary control (incontinence) when sneezing or coughing. Which muscles of the pelvic floor should be strengthened by exercise to help control this problem?
3. What steps might be taken to minimize atrophy of skeletal muscles in patients who are confined to bed for prolonged times?
4. As lactic acid and other substances accumulate in an active muscle, they stimulate pain receptors, and the muscle may feel sore. How might the application of heat or substances that dilate blood vessels help relieve such soreness?
5. Several important nerves and blood vessels course through the muscles of the gluteal region. In order to avoid the possibility of damaging such parts, intramuscular injections are usually made into the lateral, superior portion of the gluteus medius. What landmarks would help you locate this muscle in a patient?
6. Following an injury to a nerve, the muscles it supplies with motor nerve fibers may become paralyzed. How would you explain to a patient the importance of moving the disabled muscles passively or contracting them with electrical stimulation?

REVIEW EXERCISES

Part A

1. List the three types of muscle tissue.
2. Distinguish between a tendon and an aponeurosis.
3. Describe the connective tissue coverings of a skeletal muscle.
4. Distinguish among deep fascia, subcutaneous fascia, and subserous fascia.
5. List the major parts of a skeletal muscle fiber, and describe the function of each part.
6. Describe a neuromuscular junction.
7. Define *motor unit,* and explain how the number of fibers within a unit affects muscular contractions.
8. Explain the function of a neurotransmitter substance.
9. Describe the major events that occur when a muscle fiber contracts.
10. Explain how ATP and creatine phosphate function in muscle contraction.
11. Describe how oxygen is supplied to skeletal muscles.
12. Describe how an oxygen debt may develop.
13. Explain how muscles may become fatigued and how a person's physical condition may affect tolerance to fatigue.
14. Explain how the actions of skeletal muscles affect maintenance of body temperature.
15. Define *threshold stimulus.*
16. Explain *all-or-none response.*
17. Describe the staircase effect.
18. Explain *recruitment.*
19. Explain how a skeletal muscle can be stimulated to produce a sustained contraction.
20. Distinguish between a tetanic contraction and muscle tone.
21. Distinguish between concentric and eccentric contractions, and explain how each is used in body movements.
22. Distinguish between fast-contracting and slow-contracting muscles.
23. Compare the structures of smooth and skeletal muscle fibers.
24. Distinguish between multiunit and visceral smooth muscles.
25. Define *peristalsis,* and explain its function.
26. Compare the characteristics of smooth and skeletal muscle contractions.
27. Compare the structures of cardiac and skeletal muscle fibers.
28. Compare the characteristics of cardiac and skeletal muscle contractions.
29. Distinguish between a muscle's origin and its insertion.
30. Define *prime mover, synergist,* and *antagonist.*

Part B

Match the muscles in column I with the descriptions and functions in column II.

I

1. Buccinator
2. Epicranius
3. Lateral pterygoid
4. Platysma
5. Rhomboideus major
6. Splenius capitis
7. Temporalis
8. Zygomaticus
9. Biceps brachii
10. Brachialis
11. Deltoid
12. Latissimus dorsi
13. Pectoralis major
14. Pronator teres
15. Teres minor
16. Triceps brachii
17. Biceps femoris
18. External oblique
19. Gastrocnemius
20. Gluteus maximus
21. Gluteus medius
22. Gracilis
23. Rectus femoris
24. Tibialis anterior

II

A. Inserted on the coronoid process of the mandible
B. Draws the corner of the mouth upward
C. Can raise and adduct the scapula
D. Can pull the head into an upright position
E. Consists of two parts—the frontalis and the occipitalis
F. Compresses the cheeks
G. Extends over the neck from the chest to the face
H. Pulls the jaw from side to side
I. Primary extensor of the elbow
J. Pulls the shoulder back and downward
K. Abducts the arm
L. Rotates the arm laterally
M. Pulls the arm forward and across the chest
N. Rotates the arm medially
O. Strongest flexor of the elbow
P. Strongest supinator of the forearm
Q. Inverts the foot
R. A member of the quadriceps femoris group
S. A plantar flexor of the foot
T. Compresses the contents of the abdominal cavity
U. Largest muscle in the body
V. A hamstring muscle
W. Adducts the thigh
X. Abducts the thigh

Part C

Which muscles can you identify in the bodies of these models whose muscles are enlarged by exercise?

W E B   C O N N E C T I O N S

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